INDIAN SCIENTIFIC HERITAGE

DR. N. GOPALAKRISHNAN

FOREWORD BY DR. R.A. MASHELKAR, F.R.S.

Indian Institute of Scientific Heritage
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About the author......

The author, Dr. N. Gopalakrishnan was born on 20th November, 1955. He took his M.Sc. Pharm. Chem (1978); M.Sc. Chemistry (1979); M.A. Industrial Sociology (1985) Degree in Journalism (1987) and Ph.D. in Biochemistry. He has been awarded the D. Lit (2002) for his outstanding contribution through the study of the scientific heritage of India. He is a Senior Scientist, in the Regional Research Laboratory, Council of Scientific and Industrial Research (CSIR) and Hon. Director of the Indian Institute of Scientific Heritage. He is the recipient of D.V. Memorial Award (1985), Gardners Award (1988), Dhingra Memorial Award and Gold medal (1990) and again D.V. Memorial Award (1993) for the achievements in the field of scientific research. He has been awarded the first NCSTC award for the popularisation of science, by the DST, Govt. of India, in 1988. He is also the recipient of the prestigious Canadian International Development Agency (CIDA) Fellowship of the Government of Canada in 1993 and was a visiting scientist in the University of Alberta, Edmonton, Canada and visited many universities in USA, Canada and many middle east countries for delivering lectures. He has six patents and fifty research papers in the scientific studies.

He has also received four awards for the literary works and has 41 books to his credit, both in scientific and cultural subjects and many popular articles on Indian Scientific Heritage.

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square the result. From this, deduct the square of the difference in latitude of the two places. Find the square root of the remainder. This is the east west difference in degrees. This divided by 6 is the time difference in Nadikas (Panchasiddhantika 3-14).

Bhaskaracharya gives a method for the calculation in a different way.

....लम्बेनाहत्य भूमेः सकलगुणहृते वृत्तसंख्यां घटीभिर्हत्वा
देशान्तरभिर्गगनरसहृते योजनाग्रम् वदन्ति ॥

Lambenaahathya bhoome: sakalagunahruthe
vrutthasankyaam ghateebhirhatvaa desaanthara
bhirgaganarasahruthe yoganaagram vadanthi

Multiply the number of yojanas of the earth's circumference by Rsine of the colatitude and divide by the radius. The result is the number of yojanas in the local circle of latitude. Multiply that, by the longitude in ghatis and divide by 65. The result is said to the distance in yojanas of the local from prime meridian (Mahabhaskareeya 2-10 (2)

Parallax in longitude: Parallax in longitude is called lambana in Sanskrit. The explanation given for the parallax is the same as the modern observations. Parallax of longitude is explained by Lallacharya as:

भूपृष्ठगतो दृष्ट्या पूर्वनतं पूर्वमेव तिथ्यन्तात् ।
पश्यति समुच्छ्रितत्वाच्छशिना रविमण्डलं पिहितं ॥
पश्यति समकलकालात् परतोऽन्तरधीयते गतं नीचं ।
तेन प्राक् पश्चिमयोः कुदलकलालम्बनमृणं स्वं ॥

Bhooprushtagatho drushtaa poorvanatham poorvameva thithyanthaath
pasyathi samucchhithathaacchasina ravimandalam pihitham
pasyathi sama kala kaalaath paratho antharadheeyathe gatham neecham
thena praak paschimayo: kudalakalaalambanamrunam svam

The observer on the surface of the earth sees the disc of the Sun obscured by the Moon even before the calculated time as he is elevated above the centre of the earth. But if the Sun is in the western hemisphere, he sees it after the calculated time when the Sun has set. I.e. after the Sun had disappeared below the horizon. So the parallax in longitude related to the radius of the earth, is subtracted from the calculated time of conjuction/eclipse, takes place in the eastern hemisphere; but added if it takes place in the western hemisphere (Sishyadhi vruddhi Tantra 16-24, 25)

The position of the actual Sun and the observer's vision vary due to the parallax. This is because of the parallax in the measurement of the longitude. Lallacharya further explains the subject of the longitude and latitude:

पूर्वापरे कुवृत्ते लम्बनलिप्तोपपत्तिरुक्ता या ।
याम्योदक् क्षितिजवशात् सा ज्ञेयावनतिलिप्तानाम्

Poorvaapare kuvrutthe lambanlipthopapatthirukthaayaa
yaamyodak kshithijavasaath saa jneyaa avanathi lipthaanaam

Whatever is the reason given for the parallax in longitude in minutes related to the eastern and western horizon, similar reason is to be understood for the parallax in latitude in minutes related to the northern and southern horizon (Sishyadhi vruddhi Tantra - 16-27)

If parallax is not taken into consideration while calculating the astronomical phenomenon, one will arrive at a wrong conclusion. Vateswara tells that a mistake is commonly committed even by the expert astronomers by following a wrong method of calculation without including the parallax in determining the time of eclipses: So great confusion prevails even amongst astronomers who are well versed in Ganita and Gola, in the case of a solar eclipse. He says "I shall show an excellent omputation which will be immensly astonishing to the

intelligent". (Veteswara siddhanta 5(1)-I). After giving a hint on the mistakes in the above lines Vateswara describes the parallax phenomenon thus:

वित्रिभलग्नसमे दिननाथे लम्बननाश इहाभ्यधिकोने ।
तद्भवति क्षयवृद्धिविधायि स्पष्टतिथेरसकृच्च सकृद्वा ।।

Vithribhalagnasame dinanaathe lambananaasa ihaabhyadhikone thadbhavathi kshayavruddhi vidhaayi spashtathithera sakruchha sakrudravaa

When the Sun's longitude is equal to that of the central ecliptic point, the lambana (the parallax of the longitude) is non existent. When the Sun's longitude is greater or lesser, the lambana exists and cause deficit or excess in the time of apparent conjuction, no matter whether it is obtained by the process of iteration or directly. (Vateswara siddhanta 5 (1)-3).

This is one of the finest descriptions given for lambana i.e parallax in longitude. Bhaskaracharya I correlated the lambana with other parameters of astronomy. When used in connection with a solar eclipse, it generally stands for the difference between the parllaxes in longitudes of the Sun and the Moon.

Meridian and time: It is well known that the time at any place has a direct bearing on its longitude. 24 x 60 min. of duration is divided into 360°. This gives the time equivalent to each degree on the circumference of earth. In olden days hours and minutes were replaced by natika and vinatikas. One day is divided into 60 natikas and one natika into 60 vinatikas. Thus degree equivalent to this time has to be taken for natika and vinatika. Bhaskaracharya I explains it:

देशान्तरघटीक्षुण्णा मध्या भुक्तिर्द्युचारिणाम् षष्ट्या
भक्तमृणे प्राच्यां रेखायाः पश्चिमे धनम् ।।

Desaanthara ghatee kshunnah madhyaa bhukthir dyucharinaam
shashtyaabhakthamrunam praachyaam rekhaayaa: paschime dhanam.

The time is calculated based on the meridian. Divide the time by 60... and the longitude is calculated. Towards the east subtract and towards the west add the number (Laghubhaskareeyam 1-31)

Time correction from meridian : Time correction is given when there is the longitudinal difference. From the meridian, the linear distance measurement is adopted for this calculation. Varahamihira explains it thus:

पञ्चाशता त्रिभिस्त्र्यंशसंयुतैर्योजनैश्च नाड्येका ।
समपूर्व पश्चिमस्थैर्नित्यं शोध्या च देया च ॥

Panchaasathaa thribhisthryamsaamyuthairyojanaischa naaddyekaa
samapoorva paschimasthairnithyam sodhyaa cha deyaa cha

One nadi for every 53 1/3 yojanas has to be deducted or added (to Ujjaini) by the people in places east and west, respectively of the Ujjaini meridian. (Panchasiddhantika 9-10)

1° is equivalent to 60/360 of natika and 1° is equivalent to 9.375 yojanas. Hence, one natika is equal to 9 375 x 6 = 56.25. This is correct value when transilated to equivalent modern unit of measurement.

Calculation of distance from prime meridian:

अक्षांशान्निगदित पत्तनांशहीनान् संहन्यान्नवनवपक्षपुष्कराख्यैः ।
अष्टाभिशरकृतिभागहीनसंख्यैश्चक्रांशैरपहृतयोजनानि कोटिः ॥
कर्णाख्यः स्वगदित पत्तनान्तराध्वा तिर्यक्स्थो जनपदभाषितो जगत्याम् ।
तत्कृत्योर्विवरपदं वदन्ति केचिदध्वानं ग्रहगणितस्य वेदितारः ॥

Akshaamsaannigaditha patthanaamsaheenaan
sambanyaannavanavapaksha pushkaraakhyas: ashtaabhisara
kruthibhaagaheenasankhyaischakraamsairapa hruthayojanaani
koti: karnaakhya: swagaditha patthanaantharaadhvaa thiryksktho

janapada bhaashitho jagathyaam thathkruthyor vruera padam
vadanthi kethidadhvaanam grahaganithasya vedithaara:

Subtract the degrees of the latitude of the places (mentioned in the list of cities in meridian) from the degrees of latitude, then multiply (degrees) by 3299 - 8/25 and divide the product by the number of degrees in a circle i.e 360 deg. Resulting yojana constitute the upright Koti. (Mahabhaskareeya 2-3,4).

The rationale of this is 1050 yojana (earth's diameter) x 3.1416 = 3298.68 i.e 3299 - 8/25 In Lakhubhaskareeya this value is taken approximately as 3299. In Mahabhaskareeya more accurate value has been used.

Sunrise related to meridian : Countries situated on either side of the meridian have Sunrise at different times. Standard reference line for Sunrise is the meridian, and suitable corrections are given to arrive at the longitude of the places depending upon the Sunrise of those places as stated earlier: To the mean longitude of the places in the meridian passing through Lanka, Ujjaini and Himalaya (are applied) correction for difference in terrestrial longitudes of the results are for places east or west of the meridian (Sishyadhi vruddhi Tantra 1-42).

पश्चात् पश्चादर्कः प्राक्प्राक् च यतोऽभ्युदेति रेखायाः ।
तद्देशान्तरजातं तेन स्वमृणं ग्रहे क्रियते ।।

Paschaath paschaadarka: praak praak cha yathoabhyude thi rekhaayaa:
thaddesaan thara jaatham thena svamrunam grahe kriyathe

As the Sun rises first at a place which is to the east of the prime meridian line and then at a place which is west. Correction for terrestrial longitude is applied positively or negatively as the case may be (Sishyadhi vruddhi Tantra 16-6)

Celestial latitude and longitude: Terrestrial latitudes and the longitudes were commonly used. Similarly, celestial latitudes and

longitudes were also used. The celestial bodies were recognised and their places were fixed according to the celestial parameters. One example is cited:

नन्दसूर्यरससूर्यभानवो दिग्गुणः शरकला कुजादितः
वेदलोचनगजाङ्गरवेन्दवः पातजाः स्युरथ दिग्गुणलवाः

Nandasooryarasa soorya bhanavo digguna: sarakalaa kujaaditha:
vedalochana gajangaravendava: paathajaa: syuratha digguna lavaa:

Latitude of the Mars, Mercury, Jupiter, Venus and Saturan when at their mean distance from the earth are respectively 9, 12, 6, 12, and ......, each multiplied by 10. 4, 2, 8, 6 and 10 each multiplied by 10 are respectively the degree in longitudes of the nodes of the above planets (Sishyadhi vruddhi Tantra 10-5)

Here the latitudes and longitudes mentioned are celestial parameters.

Other parameters related with latitudes and longitudes : Using latitudes and longitudes geographical parameters could be calculated, as done in modern astronomical calculations. Two such examples are given below:

इष्टापक्रमगुणितामक्षज्यां लम्बकेन हत्वा या ।

Ishtaapakrama gunithaam akshajyaam lambakena hathvaa yaa

The Rsine of the latitude multiplied by the R sine of the given declination and devided by the Rsine of colatitude gives the earthsine (Aryabhateeyam 4-26a)

स्फुटार्कदोर्ज्या जिनागजीवया हता हृता व्यास दलेन जायते ।
अपक्रमज्याथ पलप्रभाहता भवेत् क्षितिज्या रविभिर्हृता सा ।।

Sphutaarkadorjyaa jinabhaagajeevayaa hathaa brutha vyaasa dalena jaayathe apakramajyaatha pala prabhaahatha bhaveth kshithijyaa ravibhirhruthaa saa

The Rsine of the true longitude of the sun multiplied by

the R sine of 24 ° and divided by the radius gives the Rsine of the declination. This multiplied by the equinoctial midday shadow and divided by 12 gives the earthsine or kutijya (Sidhyadhi vruddhi Tantra 2-17)

Detailed explanations of this subject are given in Vateswara siddhanta, Laghubhaskareeya and Mahabhaskareeya.

Given above are only a few examples, on the scientific knowledge about earth. Much more are available in the books referred to above. Some of the information still stands novel with high scientific content.

The Sun and the moon

In puranas many stories of the celestial bodies, particularly on the Sun and the moon are given. Indian scientific approach of astronomy and mathematical astronomy, had absolutely no bearing on the puranic stories. The fact that the Sun is a globe of fire was defined thus:

अग्निमयं गोलाकारमुक्तयोजनप्रमाणं आदित्यमण्डलम् ।

Agnimayam golaakaaramukthayojanapramaanaam aadithyamandalam

Spherical shaped Sun with long, diameter is full of fire (Sankaranarayana-bhashyam for Laghubhaskareeyam 4-4 page 70)

The position of the Sun from the earth was determined accurately and concluded that the distance between the Sun and the earth is maximum at 78° from the first point of Aries which falls on July 3rd. Similarly the nicha point, is 180 to the other point which falls on Jan 3rd. Detailed discussion on this subject has been given earlier in this text.

रवेर्मन्दोच्चस्य राशिद्वयमष्टादश भागाश्च !

Ravermandocbbasya raasidvyamashtaadasa bhaagaascha

The apogee of the Sun is 78° (Sishyadhi vruddhi Tantra 2-9)

It has also been explained in signs and degree values separately. Apogees of the Sun is two sign and 18 degrees (Mallikarjuna suri 2-9)

The distances between the earth and the Sun and that of the moon were calculated. The values are not accurate however these lines show that efforts were undertaken to find out the distance of the Sun and the moon from earth. This was not a subject of interest in puranas, whereas these information have great significance in the astronomical calculations on eclipse, positions, rate of motion, etc., of these celestial bodies:

विषयनागशरङ्कशराब्धयो दिनकृतः खलु योजना श्रुतिः
तुरगशैलहुताशकृताग्नयः शशिधरस्य कुमध्यतदन्तरम्

Vishayanaaga sarankasarabdhayo dinakrutha: khalu yojanaasruthi:
thuraga sailahuthaasakruthaagnaya: sasidharasya kumadhyathadantharam

The mean distance of the Sun from the earth's centre is 459585 yojanas and that of moon is 34377 yojana (Sidhyadhi vruddhi Tantra 5-4).

There is a scientific basis in the distance calculation given above, as mean distance. Because the orbit of revolution of these are known to be elliptical, it cannot be a fixed value. The apogee distances are 5565574.3km and 416305.5km. The method for calculating true distance for a fixed time was also known.

निजमृदुश्रवणेन हते श्रुती त्रिभगुणेन हृते भवतः स्फुटे ।
श्रवणमध्यमभुक्तिहतोऽथवा निजनिजस्फुटभोगविभाजितः ।।

Nijamrudusravanena hathe sruthee thribhagunena hruthe
bhavatha: sphute sravanamadhyamabhukthihatho athavaa
nijanija sphutabhogavibhaajitha:

When the mean distance are multiplied by their respective mandasphuta (hypotenuse) and divided by radius, the results,

are their correct distances. Or the mean distances multiplied by the mean motion and divided by the true motion gives the correct distance of the Sun and the Moon from earth (Sishyadhi vruddhi Tantra 5-5)

The mean motion of the Sun (infact that of the earth) was calculated using a complicated method by Manjulacharya in Laghumanasa. It is based on a previously fixed and corrected position of the Sun over a period, which is known as the position of the epoch year. From the corrected position further calculations are done, for the required time. This quotation shows how the mean motion of the Sun was calculated.

द्युगणो/धो दशघ्नाब्दयुतः खगाप्तवर्जितः
अष्टघ्नाब्दोनितो/र्कांशाः प्रक्षेप्यो/ब्दाष्टमः कलाः

Dyuganoadho daraghnaabdayutha: khagaapthavarjitha:
ashtaghnaabdonitho arkaamsaa: prakshepyoabdaashtama: kalaa:

Set down the Dyugana in two places - one below the other - In the lower place add 10 times the years elapsed since the epoch and divide by 70. Deduct the quotient from the Dyugana put down at the other place; further subtract eight times the years elapsed from the epoch year. Whatever is thus obtained is in degrees. To this, add minutes equal to 1/8 of the number of years elapsed. This will give the mean motion of the Sun since epoch. (Laghumanasa 2-3).

This is mathematically summarised as follows

The Sun's mean motion since epoch

D - (D+10Y)/70 - 8Y degrees + y/8 min. Where D is the Dyugana and Y the number of years elapsed since the epoch.

Similarly the Moon's position is also given by Manjulacharya in Laghumanasa:

विष्वघ्नो द्युगणो द्विष्ठस्त्रिघ्नाब्दद्युगणोनितः
अष्टाङ्गाप्तजिनघ्नाब्दयुतो भगादिकः शशी ।।

Vishaghno dyugano dvishtastbrighnaabdadyuganonitha:
ashtaangaapthajinaghnaabdayutho bhagaadhika: sasee

Set down 13 times Dyugana in two places. In one place diminish it by 3 times the years elapsed and also by Dyugana. Divide that by 68. Add what is thus obtained as well as 24 times the years elapsed to the quantity put down at other place - this will give the mean motion of the moon since the epoch (Laghumanasa 2-4).

I.e Mean motion of moon = 13D + (13D- (D+3Y/68) + 24 Y) degrees D is Dyugana and Y, the years elapsed since the epoch. D and Y are as mentioned above.

Varahamihira gives another method for the calculation of longitude of the Sun using the number of days elapsed from the epoch.

खखरूपाष्टगुणघनात् कृताष्टनखैकवर्जिताद् द्युगणात् ।
त्रिविषयनवखकृताशा परिशुद्धान्मध्यशीतांशु: ।।

Khakharoopaashtagunaghanaath kruthaashta nakhaika varjithaad dyuganaath
thrivishayanavakhakruthaasaa parisuddhaanmadhyaseethamsu:

Multiply the ahargana with 38100 and subtract 10984 from the value, then divide by 1040953 to get the exact longitude of the Sun. (Panchasiddhantika 8-4).

Rationale of this has been discussed in detail. Ahargana is the number of days elapsed since the epoch date. This approach is scientifically correct.

Diameter of the Sun and Moon: Diameters of the Sun and Moon were calculated and applied in determining different parameters like eclipse, Sankranti crossing, etc. Diameters of the Sun and the planets have been given by Aryabhatta:

नृ-षि योजनं, ञिला भूव्यासो, र्केन्द्वोर्घिञा गिण, क मेरोः।
भृगु- गुरु-बुध-शनि-भौमाःशशि-ङ-ञ-ण-न-मांशकाः, समार्कसमाः ॥

Nr-shi-yojanam njilaa bhuvyaaso, arkendorghinjaa ginaa ka mero: bhrugu-guru-budha-sani-bhoumaa: sasi nga nja na na maamsakaa: samaarka samaa:

8000 Nr make a yojana, the diameter of the earth is 1050 yojana, of the Sun and the Moon are 4410 and 315 yojana, of Meru is 1 yojana and that of the Venus, Jupiter, Mercury, Saturn and Mars at the moon's mean distance are 1/5, 1/10, 1/15. 1/20, 1/25 of the moons diameter (Aryabhateeyam 1-7).

Except for earth, other linear values of diameters given above are wrong. Linear modern values do not agrees, but angular diameters agree with modern values. Methods for finding out the corrected angular diameter are given below·

शिवहता द्विभहृच्छशिनो गतिस्तनुकलाः स्युरिनस्य नखोद्धृताः ।
गुणितयोर्भुजगैः शरलोचनैः खरसहृद् विवरं तमसोऽथवा ॥

Sivahathaa dvibhahrucchasino gathisthanukalaa: syurinasya nakhoddhruthaa: gunithayorbhujagai: saralochanai: karahrud vivaram thamaso athaa

Angular diameter of the moon is obtained by multiplying its true motion with 11 and dividing by 272, which is in minutes. The angular diameter of the Sun is obtained by multiplying its true motion by 11/20. The difference between 8 times the true motion of the Moon and 25 times of that divided by 60 gives the angular diameter of the shadow. (Sishyadhi vruddhi Tantra 5-9)

Given here is the direct application of the Pythagorus theorem.

भानोर्बिम्बम् रविच्छेदहृताः खखकृताचलाः
शशिनः खखभूरामाश्चन्द्रमन्दहरोद्धृताः ॥

Bhanorbimbam raviccheda bruthaa: kha kha kruthaa chalaa: rasina: kha kha bhooraamaaschandramandaharodbruthaa:

7400 divided by the Sun's divisor is the diameter of the Sun's disc, in terms of minutes and 3100 divided by the moon's manda divisor is the diameter of the moon's disc, in terms of minutes. (Laghumanasa 6-3)

The manda, cheda-manda divisor are constant which are arrived at by a series of calculations by the astronomer Manjulacharya, which are 224, 97, 45, 100, 92, 320 and 63 for the Sun, the Moon, Mars, Mercury, Jupiter, Venus, and Saturn respectively and corrected by the half of manda kotijya (Laghumanasa 3-3). Correction factor given by him is 8° 8′ cos θ/2.

Angular diameter of the Sun varies at different times, when viewed from the earth, like in the noon, at rising, setting etc. This phenomenon is explained correctly:

दूरज: क्षितिजमण्डलोपगो भूमिरुद्धकिरणश्च तिग्मगु: ।
यत्सुखं समवलोक्यते तथा भात्युरुर्विकिरणश्च सोऽरुण ।

Dooraja: kshithija mandalopago bhoomirudvakiranascha thigmagu: yathsukham samavalokyathe thathaa bhaathyuruvikiranascha soaruna

When the Sun is in the horizon, it is at a higher distance. Its rays are not disrupted by the earth and it can be seen without discomfort. Sun looks big and less hot (Sishyadhi vruddhi Tantra 16-46b, 47a)

Angular diameters of the Sun and the Moon given by the ancient Indian astronomers are compared with modern values. This is given (p 439) in Vateswara siddhanta:

	Aryabhatta	Brahmagupta & Bhaskara II	Suryasiddhanta	Modern
Sun's diameter	33′	32′ 31″	32′ 25″	32′ 2″
Moon's diameter	31′ 30″	32′	32′	31′ 8″

Dr. K.S. Sukla, the commentator of the Mahabhaskareeya has compared the diameter of the Sun and the Moon in his book. (5-2)

Diameter	Bhaskara I (Yojana)	Sripati (Yojana)	Bhaskara II (Yojana)	Modern (Miles)
Sun's diameter	440	6522	6522	86400
Sun's distance	459585	684870	689377	92900000
Ratio*	.009596	.009523	.009467	.0093
Moon's diameter	315	480	480	2160
Moon's distance	34377	51566	51566	238900
Ratio*	.009163	.009308	.0093308	.009

* Ratio : diameter / distance

Since the ratio of the diameter and the distance of the Sun and the Moon agrees correctly, calculations using distances and diameters (when they come as a ratio factor) also agree with modern astronomical calculations, even though the linear values of the diameters and distances do not agree with those of modern values.

The Sun projection on rising or setting line: During Sunrise and Sunset, it can be seen that there exists a projection above the rising/setting line. This projection is called sankvarga. While discussing the parallax phenomenon Sankvarga has also been discussed earlier. Method for calculating Sankvarga is:

विषुवज्जीवागुणितः स्वेष्टःशङ्कुः स्वलम्बकेन हृतः ।
अस्तमयोदयसूत्राद् दक्षिणतः सूर्यशङ्कवग्रम् ।।

Vishuvajyeevaagunitha: sveshta: sanku: svalambakena brutha:
asthamayodayasoothraad dakshinatha: sooryasankvagram

Multiply the Rsine of the Sun's altitude for the given time by the Rsine of latitude and divided by the Rsine of colatitude. The result is the Sun's sankvagra (Aryabhateeyam 4-29)

Modern astronomy defines. sankvagra-parllx is the distance of the Sun's projection on the plane of the observer's horizon from the Sun's rising and setting line.

Parallax of the Sun and the Moon: The Sun and the Moon may shift from their true positions due to the parallax on observation. This parallax has been calculated scientifically.

मध्यज्योदयजीवासंवर्गे व्यासदलहृते यत् स्यात्
तन्मध्यज्याकृत्योर्विशेषमूलं स्वदृक्षेपः ।।

Madhyajyodaya jeevaasamvarge vyaasadalahruthe
yath syaath thanmadhyajyaa kruthyorviseshamoolam sadrukshepa:

Divide the product of the Madhyajya (Rsine of the zenith distance of the meridian ecliptic point) and the udhayajya (Rsine of the amplitude of rising point of ecliptic) by the radius. Square root of the difference between the squares of that result and the Madhyajya is the Sun's or the Moon's Parallax-drkshepa - (Aryabhateeya 4-33)

Declination of the Sun and the Moon: Definition of declination are given in the beginning of the text.

जीवा/ध्यर्धशतांशघ्नैकाषष्टिर्दिनेशकाष्ठाज्या ।
चन्द्रस्य सविक्षेपस्तदपक्रमो राशिपादेभ्यः ।।

Jeevaa adhayardha sathaamsaghnaikaashashtirdinesa kaashtaajyaa
chandrasya savikshepasthadapakramo raasipaadebhya:

The Sun's declination is found by multiplying the sine of its longitude by 61 and dividing by 150. Its arc is declination.

The declination of the Moon obtained thus is the mean value. If the true declination is to be found out, it is the mean declination + latitude Intervals of the declinations for each quarter signs (7½°) are also given in the next stanza (Panchasiddhantika 4-16)

Description about the Moon : The Moon is a satellite of earth and it has a prominent role in the astrological studies. Hence it is included in the list of Navagrahas. Many mathematical calculations made by Indians and data, like revolution, rotation, rate of motion, position, ascending nodes, eclipses, horns.... etc., related to the moon agree with modern data. About the shining of Moon, Lallacharya says thus:

सलिलमये शशिनि रवेर्दीधितयो मूर्च्छितास्तमो नैशम् क्षपयन्ति
दर्पणोदरनिहिता इव मन्दिरस्यान्तः ।।

Salilamaye sasini raverdeedhithayo moorcchithaasthamo naisam kshapayanthi darpanodaranihithaa iva mandirasyaantha:

Just as the Sun rays reflected by a mirror dispel the darkness in a room, the Sun's rays reflected by Moon dispel the blind darkness of night on the earth.

This explanation is given by Lallacharya in Sishyadhi vrudhi Tantra (16-39) and has also given by Varahamihira in Panchasiddhantika (13-36)

Rising and setting of the Moon: Unlike any other celestial body, the rising and setting of the Moon vary every day. And also its size and shape. Hence the study of moon needs a different approach from that followed for other celestial bodies. The rising and setting of Moon has been well documented and Varahamihira gives methodology for the calculation):

याम्योदग्विक्षेपद्विषुवद्भघ्नाद्रविभिरवाप्तांशाः
उदये शशिनो वृद्धिःक्षयो विपर्यस्तमस्तमये ।।

Yamyodagvikshepadvishuvadbhaganaadravi bhiravaapthaamasaa:
udaye sasino vruddhi:kshayo viparya sthamasthamaye

Multiply the Moon's latitude in degrees by equinoctial shadow and divide by 12. Add the resulting degree to the longitude of the Moon, or subtract from it, according to the Moon's latitude is south or north, if the times of daily moonrise is to be computed. If the times of daily moonset is to be found out, reverse the addition, and subtract.

I.e. subtract and add respectively (Panchasiddhantika 5-8) i.e Moonrise and Moonset can be calculated from its celestial latitude and shadow.

Visibility correction of the Moon: Visibility correction of the Moon is applicable for calculating various lunar astronomical parameters. Hence it is an important observation in the astronomical studies. Nakshtra (star) of the day is calculated by finding out the position of the Moon in the group of stars (constellation). To get the correct position of the Moon, its visibility is to be corrected.

स्वष्टदेशपलजीवया हतां क्षिप्तिमिष्टशशिजां समाहरेत् ।
लम्बकेन यदवाप्तमुत्तरे शोधयेदुदयगे निशाकरे ।।
अस्तगे धनमुशन्ति तद्विदो दक्षिणे विधिरयं विपर्ययात् ।

Swashtadesapala jeevayaa hathaam kshipthimishta sasijaam samaahareth
lambakena yadavaaptha mutthare sodhayedudhaage nisaakare
asthage dhanamusanthi thadvido dakshine vidhirayam viparyayath

Multiply the moon's latitude for the desired time by Rsine of latitude of the local place and divided the product by Rsine of colatitude; whatever is thus obtained says the learned, should be subtracted from the moon's longitude in the case of rising of the moon (in the eastern hemisphere) and added to the Moon's longitude in the case of setting moon (western hemisphere) provided that the moon is to the north of the ecliptic (i.e moon's

latitude is north). When the moon is south of the ecliptic, the rule is reversed. This is Drkkarma (Mahabhaskareeya 6-1, 2a).

In modern astronomy Drkkarma is called the visibility correction. Equation given in the above stanza can be mathematically summarised as follows: The Ayana Drkkarma = R vers (m-90°) x R sin θ x moon s latitude/ RxR where m is the moon's longitude and θ is the Sun's greatest declination.

Full moon and new moon: Astronomers had the scientific information on many aspects of the moon which has perfect rational background..

केनकारणेनेन्दोर्मण्डलस्य वृद्धिक्षयौ दृश्येते । नैवमण्डलस्य क्षयवृद्धी, कुत:? ज्योत्स्नाया ज्योत्स्ना तावदादित्याभिमुखस्य चन्द्रबिंबस्योपरि दिने दिने पूर्वपक्षे भूगोलस्थाने सुकरदर्शनादूर्धत इव दृश्यते ।

Kenakaaranenendormandalasya vruddhikshayow drusyathe naivamandalasya kshayavruddhee, kutha: jyothsnaayaa jyothsnaa thavadaadithyaabhimukhasya chandrabimbasyopari dine dine poorvapakshe bhoogolasthaanam sukaradarsanaadvardhatha iva drusyatha

By what reason the Vruddhikshaya of the moon occurs? It is never the real change in the growth or destruction of the moon! For the one who obseves from the earth in the beginning of the lunar month, the area where the sunrays fall increases steadily day by day, and that lighted area of the moon becomes easily visible (Sankaranarayanabhashya for Laghubhaskareeyam 4-4p 71). No further explanation is required for the commentary of Sankaranarayana.

सकलमसितं मासान्ते दलं शशिमण्डले धवलमखिलं पक्षान्ते
स्यान्नृलोचनगोचरं ।
असितमसिते शुक्ले शुक्लं क्रमादुपचीयते रविमभि यत:
प्रालेयांशोस्तथा च विमुञ्चत: ।।

Sakalamasitham maasanthe dalam sasimandale

dhavala makhilam pakshaanthe syaannrulochanagocharam
asithamasithe sukle suklam kramadupacheeyathe ravimabhi
yatha: praaleyaamsosthathaa cha vimunchatha:

At the end of lunar month- the lower half of the disc of the moon, to the people of the earth, is completely dark, but at the end of the first fortnight (purnima) it is completely shining since the moon approaches the Sun. In the dark half of the lunar month, its dark portion gradually increases. Light half of the moon recedes from the Sun. So the illumunated portion gradually increases. (Sishyadhi vrudhi Tantra 16-38)

Calculation of illuminated portion of moon: There are two portion for the moon except on the new moon day and the full moon day. Method for the calculation, of the illuminated and non illuminated portion of the moon, was followed as:

व्यर्कशीतकरभागसञ्चयः शुक्लमिन्दुदलसङ्गुणो भवेत् ।
व्योमनन्दविहृतः सितासितं तद्वदेव भगणार्धवर्जितम् ।।

Vyarkaseethakarabhaagasanchaya: suklamindudalasanguno bhaveth
vyomanandavihrutha: sithaasitham thadvadeva
bhaganaardhavarjitham

The difference in the true longitude of the Sun and the moon in degree, multiplied by the radius of the moon and divided by 90 gives the illuminated portion of the moon (in the light half). When the above difference is diminished by 180° and the remainder is multiplied by the radius of the moon and divided by 90°. The result is the dark portion in the dark half (Sishyadhi vruddhi Tantra 9-13).

This method gives the correct radius of the portion of the moon which is illuminated. Detailed descriptions of this stanza are given by Mallikarjuna Suri in his commentary to Sishyadhi vruddhi Tantra. Bhaskaracharya I and Varahamihira have also discussed the subject with great mathematical elaborations.

Longitude of the moon: Longitude of the planets and the Sun have been discussed earlier under the subject of longitudes and latitudes. Two quotations are reproduced to show that longitude and latitude of the moon were measured scientifically. Lallacharya has given a method to determine the longitude of the moon, as it was suggested for the Sun:

भुजङ्गनन्दाष्टवसुस्वराहते शराक्षिषड्बाणशरेन्दुलोचनै :
हृते दिनानां निचयो/थवा भवेन्मृगाङ्कमूर्तिर्भगणादिकं फलम् ।।

Bhujanganandaashtavasusvaraahathe saraakshushadbhaana
sarendulochanai. hruthe dinaanaam nichayoathavaa
bhavenmruganka moorthirbhaganaadhikam phalam

Ahargana multiplied by 78898 and divided by 2155625 gives mean longitude of the moon (Sishyadhi vruddhi Tantra 1-19).

As mentioned earlier the Ahargana is the number of days since the epoch era. The time of moon rise and the Sun are correlated by Lallacharya, by means of degree angle longitude of sunset and moon rise. If they have the same true longitude and are apart by 180° then:

भवनषट्कयुतेन विवस्वता भवति चेत् सदृशो हिमदीधितिः
समुदेति तथास्तमुपेयुषा निशि महानमहानपि वासरे

Bhavanashatkayuthena viasathaa bhavathi
cheth sadruso himadeedhithi. samamudethi
thethamupeyushaa nisi mahanamahaanapi vaasare

If true longitude of moon is the same as true longitude of the Sun at sunset incresed by 6 signs, moon rises at the same time as Sun sets If greater, moon rises after and if lesser it rises before sunset. (Sidhyadhi vruddhi Tantra 8-9).

This explanation is given after discussing the two types of visibility corrections. If the moon rises at the same time of sunset, it means that Sun and moon are 6 signs (180° apart). This

observation agrees perfectly with modern scientfic notes. When the Sun and the moon are at 180°, that is full moon day.

Eclipse

Ancient Indian astronomical knowledge got a set back in this subject of eclipse due to the over emphasis on puranic stories. Many superstitions and rituals were followed on the basis of these stories. A part of the astrological explanations also played a negative role. The real astronomical knowledge got camoflaged. At the same time ancient Indian astrologers could predict the time of eclipse and prove it by original observation. One has to predict the eclipse by mathematical calculations, there should be a sound astronomical background for that. There are ancient books (in some books a number of chapters) fully devoted for the studies on the mathematical calculations and predictions of the solar and lunar eclipses. Puranic stories have never been quoted anywhere in the astronomical books. Sankaranarayana even criticises the puranic story while explaining the eclipse.

किमर्थम् असुरः कश्चिद्राहुर्नाम सैंहिकेयोऽर्कं चन्द्रं च ग्रसत इति श्रूयते ।
सापि पौराणिक श्रुतिरेव । कः पुनरिह राहुरित्युच्यते ॥

Kimartham asura: kaschidraahurnaama saimhikeyoarkam chandram cha grasatha ithi srooyathe sraapi pouraanika sruthireva! ka: punariha raahurithyuchyathe

What does it mean that Asura is responsible for the eclipse? Others say that a snake Rahu swallows the Sun and the Moon! Those are puranic stories! Then what is called the Rahu? (Sankaranarayana in Laghbhaskareeya 4-4) After criticising these statements, he clearly gives the cause of eclipse:

अत एव भूच्छाया चन्द्रग्रहणस्य कारणं

Atha eva bhoocchayaa chandragrahanasya kaaranam

That is why it is said that the shadow of the earth is the

cause for the lunar eclipse (Sankaranarayana 4-4p 71)

Lallacharya declares clearly how the superstition of R came into existence when so many facts are clearly observable in eclipses:

ग्रहणे ग्रहमोक्षदिशो रविशशिनोः खण्डकालवैचित्र्यात् ।
शशिभूच्छाये कारणमकारणम् राहुरिति सिद्धम् ।

Grahane grahamokthadiso ravisasino: kanddakaala vachithryaath sasibhoocchaaye kaaranamakaaranaam raahurithi siddham

In solar and lunar eclipses, the parts of disc are different and durations are different, direction of contact and separation are different, the cause is the moon for solar eclipse and earth s shadow in lunar eclipse. It is thus esablished that Rahu is not the cause for eclipse (Sishyadhi vruddhi Tantra 16-34)

तिमिरमावरणं हिमदीधितेर्दिनकरस्य निशाकरमण्डलम् भवतिमण्डल खण्डयुतिस्तयोस्तदभिधावरणावरणीययोः

Thimiramaavaranam himadeedhitherdinakarasya nisaakaramandalam bhavathimandala khandayuthisthayo sthadabhi dhaavaranaavaraneeyayo:

Shadow is the moon's obscuring body and the moon is the Sun's obscuring body There are total and partial eclipses of the obscured body caused by the obscuring body. The eclipse is named (as grahana means that is holding) after the eclipsed portion or the obscured body (Sishyadhi vruddhi Tantra 5-10)

Lallacharya also codemns the 'demons theory' of the cause of eclipse, thus:

असुरो यदि मायया युतो नियतोऽतिग्रसतीति ते मतम् ।
गणितेन कथं स लभ्यते ग्रहकृत्पर्व विना कथञ्चन ।।

Asuro yadi maayayaa yutho niyatho athigrastheethi thematham ganithena katham sa labhyathe grahakruthparva vinaa kathanchana

If you are of the opinion that an artifical demon is always the cause of an eclipse by swallowing, then how is it that an eclipse can be determined by means of calculations. Moreover why is then not an eclipse occur on a day other than the day of new or full moon (Sishyadhi vruddhi Tantra 20-22).

Even 1500 years ago, perhaps earlier than this, there was a clear astronomical understanding of eclipse. It appears the first clear written statement on the eclipse appeared in Aryabhateeya:

छादयति शशी सूर्यं, शशिनं महती च भूच्छाया ।

Cchadayathi sasi sooryam sasinam mahathee cha bhoocchaayaa

Moon covers (shadows) the Sun and the great shadow of the earth covers the moon which causes the eclipse (Aryabhateeyam 4-37)

Nilakanta has defined the shadow:

तद्भाग एवान्तरीक्षे तद्रश्मिराहित्याद् भूच्छायेत्युच्यते ॥

Thadbhaaga evaanthareekshe thad rasmiraahithyaad bhoocchaayethyuchyathe

That portion in the space where the rays/ light is absent is called the shadow (Nilakanta s commentary to Aryabhateeya, golapada : 4-37).

Sankaranarayana has also shown the scientific approach of explaining the shadow very systematically :

भूमण्डलस्य गोलाकार भपञ्जरमध्य प्रतिष्ठितस्य खमध्यस्थस्य छाया भूगोल परिणाहमूला गोपुच्छाग्रा सूर्यदिग्विपरीत दिगनुसारिणी तत्तुल्यभ्रमणगतिः कुम्भस्यातपस्थस्य छायेव यावता दीर्घत्वेन दृश्यते ....

Bhoomandalasya golaakara bhapancharamadhya prathishtithasya khamadhyasthasya cchaayaa bhoogola parinaahamoolaa gopucchaagraa sooryadigvipareetha diganusaarinee thatthulyabhramana gathi: kumbhasyaathapasthasyacchaayeva yaavathaa deerghathvena drusyathe

As the shape of the earth is spherical and it is placed in the centre of the space (bhapanchara madhya). Shadow of the earth having a circumference proportionate to the circumference of the earth, moves in the opposite to the direction of the Sun's movement, with the same speed, similar to the shadow generated by a spherical vessel, and that is the shadow which can be seen from a distance (Sankaranarayana Laghubhaskareeya page 71-72)

Here Sankanarayana was of the view that Sun is moving. Hence he has given the statement in the opposite direction of the Sun. However it is the earth which revolves and essence of the statement is the same. Aryabhatta has clarified possible days of the eclipses and the conditions required for the same, and what causes the eclipse (Aryabhateeya 4-38):

स्फुटशशिमासान्तेऽर्कं पातासन्नो यदा प्रविशतीन्दुः
भूच्छायां पक्षान्ते तदाधिकोनं ग्रहणमध्यम् ।।

Sphutasasimaasaanthearkam paathaasanno yadaa pravisatheendu:
bhoocchaayaam pakshaanthe thadadhikonam grahanamadhyam

At the end of a lunar month, the moon, lying near a node enters the Sun or at the end of a lunar fortnight, enters the earth's shadow, it is more or less the middle of an eclipse, in the former case it is solar eclipse and in the latter case lunar eclipse is caused.

More scientific facts on eclipses:

At the end of a lunar month, moon, which is nearer to the Sun as per degree measurement, enters (shadows-gets covered) the Sun's disc, similarly in the end of a paksha the moon enters the shadow of the earth, which results in the eclipse (Aryabhateeyam 4-39)

This is well known scientific observation. Only on a full moon day or a new moon day lunar or solar eclipse take place, if ever an eclipse is taking place. Varahamihira has given an important statement on eclipse Showing a thorough knowledge of the solar system. He says:

सूर्येन्दुभगणधात्रीसंस्थानविदोऽधिकृत्य कथयामि ।
ग्रहणं सदैव भानोः स्थानविशेषात् क्वचिद्दृश्यम् ।।

Sooryendu bhaganadhaathree samsthaana vidoadhikruthya kathayaami
grahanam sadaiva bhaano: sthaanaviseshaath kvachidadrusyam

As I know the relative position of the Sun, the moon and other asterisms, I say that the solar eclipse is taking place always at some place in space. Due to the difference of place only at some places they are seen (Panchasiddhantika 15-1)

It is true that the earth's shadow always revolves in the solar system. Whichever is the planet/body that happens to enter this shadow, then an eclipse occurs. As long as no body enters into this darkness, it will not be eclipsed. Possibility of seeing an eclipse by an observer is mentioned by Varahamihira:

संक्षेपसूत्रवशातः शशिनाऽऽव्रियते दिवाकरो येषाम् ।
तेषां सूर्यग्रहणं स च देशः प्रतिदिनं क्वापि ।।

Samkshepasoothravasatha: sasinaavriyathe divakaro yeshaam
theshaam sooryagrahanam sa cha desa: prathidinam kvaapi

If a line is drawn between the observer and the Sun, and if the moon happens to be in the line, whichever place the observer stands, he can see the solar eclipse, this is happening any day anywhere (Panchasiddhantika 15-3)

As mentioned earlier, the Sun is observed by people in different countries in different ways. It may be rising, setting or midday Sun. When a solar eclipse takes place, observers may or may not see it as told by Varahamihira:

अस्माकमुदयसमये येषामल्पास्तगो दिवसनाथः
मध्याह्नो वा येषां तेषामपि न युगपद्ग्रहणं ।।

Asmaakamudayasamaye yeshaamalpaashtthago divasanaatha:
madhyaahno vaa yeshaam theshaamapi na yugapadagrahanam

If a solar eclipse takes place during sunrise for us, the same eclipse will not be observed at the same time where the Sun sets, so is the case where is noon (Panchasiddhantika 15-8)

He has also mentioned the reason for not seeing an eclipse in the north pole:

न कदाचिदपि ग्रहणं मेरुगता मेरुसन्निकृष्टा वा ।
पश्यन्ति तिग्मरश्मेः अनुच्चभावाद्रविहिमांश्वोः ।।

Na kadaachidapi grahanam merugathaa merusannikrushtaa vaa pasyanthi thigmarasme: anuchha bhavaadravihimaamsvo:

Those who are in the north pole and near by places, can never see a solar eclipse. This is because the Sun and the moon never come in the same line, for them. (Panchasiddhantika 15-5)

अर्केन्दु दृष्टिवेधो न मेरुगानां कदाचिदपि भवति पार्श्वस्थास्ते
विवरं पश्यन्ति सदैव सूर्येन्दोः ।।

Arkendu drushtivedho na merugaanaam kadaachidapi bhavathi parsvasthaasthe vivaram pasyanthi sadaiva sooryendo:

In the north pole the Sun and the moon never comes in the line of the observer's viewpoint. They always see the Sun and the moon at a difference only. Hence the eclipse is not seen for them. (Panchasiddhantika 15-6)

Beginning and ending of solar eclipse is explained here·

जलदवदिन्दुर्दिनपं छादयति समागतो यतः पश्चात् ग्रहणमतः
पश्चात् प्राग्भागे दिनकरे मोक्षः ।।

Jaladavadindurdinapam cchadayathi samaagatho yatha. paschaath prahanamatha: paschaath praagbhaage dinakare moksha:

In a solar eclipse since the moon comes from the west like a cloud and obscures the Sun, contact takes place in the west and separation in the east (Sishyadhi vruddhi Tantra 16-29)

प्रत्यङ्मुखं व्रजन्त्यां पूर्वाभिमुखो व्रजति शशी यस्मात् ।
तस्मात् प्राक् प्रग्रहणं पश्चान्मोक्षः शशिरश्मेः ।।

Prathyangmukham vrajanthyaam poorvaa bhimukho vrajathi sasi yasmaath
thasmaath praak pragrahanam paschaanmoksha. sasirasme.

In a lunar eclipse the moon moving eastward enters the shadow of the earth which is moving westward. Contact takes place in the east and separation in the west. (Sidhyadhi vruddhi Tantra 16-32)

Horn formation in the solar and lunar eclipses is well explained scientifically:

आवरणस्य लघुत्वात् तीक्ष्णविषाणोऽर्धखण्डितः सविता ।
भवति स्थितिश्च लघ्वी प्रतिविषयं ग्रासनानात्वात् ।।

Aavaranasya laghuthvaath theekshna vishaano ardhakhanditha: savithaa bhavathe sthithischa laghvee prathivishayam graasanaanaathvaath

(In a solar eclipse) the obscuring body being smaller in size, the Sun when half eclipsed has pointed horns. The duration of the eclipse is short and the obscured portion appears differnt on observation from different places (Sishyadhi vruddhi Tantra 16-30)

छादकबिम्बमहत्वाद् विषाणयोः कुण्ठतार्धसंछन्ने चन्द्रेस्थितिश्च
महती भवति न च ग्रासवैचित्र्यम् ।।

Cchaadaka bimba mahathvaad vishaanayo.
kuntathaardha samcchanne chandresthithischa
mahathee bhavathi na cha graasa vaichithryam

As the disc of the earth's shadow which is the obscuring body in a lunar eclipse- is big, the horns of moon, in half eclipse in blunt. The duration of eclipse is long and the obscured portion does not appear different from different places (Sishyadhi vruddhi Tantra 16-33)

Absence of parallax in a lunar eclipse has been described by Lallacharya.

प्रविशति यद् भूच्छायावृत्तं त्रैराशिकात् स्वकक्षास्थम् तेन न
लम्बनमिन्दोर्नावनतिस्तुल्यकक्षत्वात् ॥

Pravısathı yad bhoocchaayaavrutthamthraıraasıkaath
svakakshyaastham thena na lambanamındornaava nathı
thulyakakshathvaath

In a lunar eclipse, the moon enters the circle of the earth's shadow, in its own orbit as shown by calculations. Since the orbit is the same, there is neither parallax in longitude nor in latitude (Sishyadhi vruddhi Tantra 16-31)

The method for calculating diameter of the shadow is given by Lallacharya.

स्फुटशशिश्रवणेन विवर्जिता गगनपञ्चककुगुणिता कुभा
अपहृता च तया प्रभया भुवो भवति योजन बिम्बमगोः फलम् ॥

Sphutasasısravanena vıvarjıthaa gaganapanchaka
kushgunıthaa kubhaa apahruthaa cha thayaa prabhayaa
bhuvo bhavathı yojana bımbamago: phalam

The length of the earth's shadow diminished by correct distance of the moon from the centre of the earth, then multiplied by 1050 and divided by itself, gives the diameter of the earth's shadow in yojanas (Sishyadhi vruddhi Tantra 5-7).

An equation is given by Man,ulacharya for calculating the diameter of the shadow:

छायाग्रहस्यषड्भोर्कि स्तन्मण्डलकलामितः
चन्द्रमार्गे शशिच्छेदहृताः खखगुणोरगाः ॥

Cchaayaagrahasyashadbhoarka sthanmandalakalaamıthı:
chandramaarge sasıcchedahruthaa: khakhagunoragaa:

Longitude of the Sun plus 6 signs (180°) is the longitude of

the shadow of a planet. Its diameter in terms of minutes, in the moon's orbit, is equal to 8300 divided by the moon's divisor (Laghumanasa 6-4).

I.e Diameter of the shadow is equal to 8300/(97° + 8°8' cos θ²). Where θ is moon's bhuja.

Calculation of the possibility of an eclipse

Prediction of the correct time of eclipse, time of contact, partial or complete eclipse, places where they are visible, duration etc. was possible by mathematical calculations. Lallacharya gives the methods.

पातितागुरविचक्रदलाभ्यां लिप्तिकाः समधिका यदि वोनाः
संहरेद्दिनतमोगतियुत्या स्युः क्रमेण दिवसा गतगम्याः
तैर्मासान्ते भवति निकटे पर्व भानोर्दिवा चेत् पक्षस्यान्ते
निशि शशभृतस्तत्र पातोन चन्द्रे यद्यंशाः स्युर्भदलरहिते भार्धतो वा
विशुद्धे चक्राच्छुद्धे भगणरहिते वा स्फुटा द्वादशांशाः ॥

Paathithaa guruvichakradalaabhyaam lipthikaa: samadhikaa yadi vonaa:
samharedinathamo gathiyuthyaa syu: kramena divasaa gathagamyaa:
thairmaasaanthe bhavathi nikate parva bhaanordivaa cheth
pakshasyaanthe nisi sasabruthasthathra paathonachandre
yadyamsa: syurbhadalarahithe bhaardhatho vaa visuddhe
chakraacchuddhe bhaganarahithe vaa sphutaa dvaadasaamsa:

Subtract the longitude of the moon's node from that of the Sun. Find the difference between this remainder and for 12 signs-(180° or 360°) - divide the result expressed in minutes by the sum of motions of the Sun and the node. The quotient gives the number of days elapsed (since the possibility of the occurence of an eclipse, if the above days are greater than for 12 signs) If less, the quotient gives the number of days to elapse (before eclipse). If these days happen to be near amaavasya - new moon day- then there is a possibility of solar eclipse during day time. If they

happen to be near purnima - full moon day - then there is the possibility of lunar eclipse during night. Subtract the longitude of the moon's node from that of the moon. If the difference between the remainder and for 12 signs lies within 12°, there is possibility of lunar eclipse. (Sidhyadhi vruddhi Tantra 7-1,2)

This method is correct and the parameters utilised for the prediction of solar / lunar eclipse are scientific.

Varahamihira has explained the method for calculating the possibility of the eclipse by knowing the longitude of the shadow. After defining correctly what he means by Rahu (shadow), he describes the method.

राहो: सषट्कृति कलां भित्वांश तच्छशाङ्क विवरांशै: ।
ग्रहणं त्रयोदशान्त: पञ्चदशान्तास्तमस्तस्य ।।

Raaho: sashat kruthi kalaam bithvaamsa thacchasaanka vivaramsai:
grahanam thrayodasaantha: panchadasaantha sthamasthasya

Subtract 1° 36′ from the longitude of the Rahu's (shadow) head or tail whichever is nearer to the moon. Take the angle difference between the Rahu and the moon. If this comes within 13°, a lunar eclipse will occur. If it is less than 15° there will only be a slight darkening possibility (only grahana chaya occurs) (Panchasiddhantika 6-2)

Sight darkening is due to the moon entering into the penumbra part of the shadow. Two parts of shadow i.e. umbra and penumbra are described in detail in the modern astronomy. The possibility of eclipse and the spread of shadow near moon has been well described by Varahamihira. More accurately, Lallacharya had gone deep into the subject for predicting the possibilities of eclipses within a duration of 6 months.

यदिपुनरवगन्तुमन्यदिष्टं ग्रहणमिहाहनि मध्यमे तदानीम् ।
शर-जिन-भ रसान् संहस्ररश्मे: शशिनि शरास्कृति सूर्य-रामबाणान् ।।

खं अतिधृति–यमाब्धि–रामबाणान् सरसि सरोरुहवैरिणश्च तुङ्गे: ।
तमसि च ख–नवाकृति क्षमाब्धीन् भलवकलाविकला विशोधिते स्यात् ।।

Yadipunaraaganthumanyadishtam grahana mihaahani madhyame thadaaneem sara-jina-bha-rasan sahasrarasme: sasini sarakruthi-soorya-raamabaanaan

kham athidhruthi-yamaabdhi raamabaanaan sarasi saroruha vairinascha thungai: thamasi cha kha navaakruthi kshamaabdheen bhalavakalaa vikalaa visodhithe syaath

If one wants to know whether there will be an eclipse after 6 months find the mean longitude of the Sun, the moon their apogee and node on that day. Then add to the first three longitudinal values these figures, respectively 5s 24° 27′ 6″, 5s 22° 12′, 53″, 0s 19° 42′ 53″ and subtract 0s 9° 22′ 41″ from the longitude of the node. (Sishyadhi vruddhi Tantra 7-9,10). Here s is sign which is equal to 30°.

Important information given here is that the addition of the finest angular values, for arriving at a conclusion astronomically The orbits of these celestial bodies and shadow move in well defined (and mathematically calculated) orbits. This process if reversed, will give whether eclipse had taken place in the last 6 months. The calculation of the position have also been given by him.

व्योमैन्द्रा सप्तवेदा यमोऽहिमकरे पक्षलब्धिर्गृहादि: षट्कं सप्तेन्दवोऽथो
भुजगहतभुजो युग्मवेदा: शशाङ्के । तुङ्गे लिप्ता:
शतं सत्रिशशि विकलिकं सैंहिकेयेऽष्टवेदा लिप्ता: पादेन हीना:
स्वमृणमवगमे पर्वण: स्याद् विधिश्च ।।

Vyomaindraa sapthavedaa yamoahimakare pakshalabdirgruhaadi: shatkam saptendavoatho bhuja gahathabhugo yugmavedaa. sasaanke thunge lipthaa: sutham sathrisasi vikalikam saimhikeye ashtaveda lipthaa: paadena heenaa. swamruna mavagame paruvna: syaad vidhischa

If one wants to know whether there was an eclipse before half a lunar month or there will be one after half a lunar month one must first find the mean longitude of the Sun, the moon, their apogees and nodes on that day. Then one must add or subtract 0s 14° 47′ 2″, 6s 17° 38′ 42″ and 100′ 13″ respectively to or from the first three mean longitudes according as the eclipse is after or before half a lunar month. This is the rule for the determination of an eclipse (Sishyadhi vruddhi Tantra 7-11)

The level of angular accuracy, Lallacharya has gone in explaining the possibilities of eclipses, is surprising. Varahamihira in Panchasiddhantika has similar method for calculating the possibility of lunar eclipse, which has been explained earlier (Panchasiddhantika 6-2).

The relation between the Sun, the moon and the formation of shadow is thus discussed by Aryabhatta:

भूरविविवरं विभजेद् भूगुणितं तु रविभूविशेषेण
भूच्छायादीर्घत्वम् लब्धम् भूगोलविष्कम्भात् ।।

Bhooravivivaram vibhajed bhoogunitham thu ravibhoovisheshena
bhoocchaayaadeerghathvam labdham bhoogolavishkambhaath

Multiply the distance of the Sun from the earth by the diameter of the earth and divide the product by the difference between diameters of the Sun and the earth; The result is the length of the shadow of the earth from the centre of the earth (Aryabhateeyam 4-39)

This gives the rational and correct method for calculating the length of the earth's shadow at moon's distance. The diameter of earth's shadow in angular units is given by Lallacharya. It is from this unit of 'angula' that the real 'angular' measurement was calculated in olden days. Angula is the average width of the fingers and it is a linear measurement.

शराहता नागयमैर्हृतार्को यमाहता चान्द्रमसीषुरामैः ।
गतिर्वियोगः फलयोर्भवेद् यत् तदेव बिम्बं तमसोऽङ्गुलादि ॥

Saraahathaa naagayamairbruthaarko yamaahathaa chandramaseeshu raamai: gathirviyoga: phalayor bhaveth yath thadeva bimbam thamaso angulaadi.

Multiply the Sun's true motions by 5 and divide by 28. Multiply the moon's true motion by 2 and divide by 35. The difference of the two quotients gives the diameter of the earth's shadow in angulas (Sishyadhi vruddhi Tantra 7-4).

From the distance of the earth and the moon, and that of the total length of the shadow the length of earth's shadow at the moon's distance is calculated correctly as followed by Aryabhatta:

छायाग्रचन्द्रविवरं भूविष्कम्भेण तत् समभ्यस्तम् भूच्छायया
विभक्तं विद्यात् तमसः स्वविष्कम्भम् ॥

Cchaayaagra chandra vivaram bhoovishkambhena thath samabhyastham bhoocchaayayaa vibhaktham vidyaath thamasa: svavishkambham

Multiply the difference between the length of the earth's shadow and the distance of moon by the earth's diameter and divide the product by the length of the earth's shadow; the result is the diameter of Tamas (shadow) in moon's distance (Aryabhateeyam 4-40).

I.e the diameter of the shadow at moon's distance is: length of earth's shadow - Moon's distance multiplied by the earth's diameter and divided by the length of the earth's shadow.

The relation of the motion, latitude, etc. of the eclipsed and eclipsing bodies are also given in Aryabhateeya (4-44):

विक्षेप वर्गसहितात् स्थितिमध्यादिष्टवर्जितान्मूलं ।
सम्पर्कार्धाच्छेध्यं शेषस्तात्कालिको ग्रासः ॥

Vikshepa vargasahithaath sthithi madhyaadishta varithaanmoolam sampakaardhacchedhyam seshasthaathkaaliko graasa:

Subtract the ishta from the semi duration of the eclipse; to that add the square of the moon's latitude and take the square root of this Sun Subtract that from the Sun of the semi diameters of the Tamas and the moon. Remainder is the measure of the eclipse at the given time.

Here the ishta is the moon's motion in longitude, relative to Tamas after the first contact. Generally ishta is given in time equivalent of ghatis. Further explanations are also given by Aryabhatta.

From the square of half of the sum of the diameters of that shadow and moon, subtract the square of moon's latitude and take square root of the difference, the result is known as the duration of eclipse in terms of minutes of arc. The corresponding time is obtained with the help of daily motion of the Sun and the moon. (Aryabhateeyam 4-41).

This according to modern science gives an approximate value of semi duration of eclipse.

According to Varahamihira, the diameter of the shadow can be calculated as follows:

रविकक्षा नवतिगुणा षडष्टदस्रोद्धृतेन्दुकक्षाया:

छेद: षट्त्रिघ्नाया लब्धेनोनश्च षड्वर्ग:

वियदर्कगुणे शशिकक्ष्यया हृते कार्मुकं तमोव्यास: ।।

Ravikakshaa navathigunaa shadashta sroddhruthendu kakshaayaa: ccheda shatthrighnaayaa labdhenonascha shadvarga: viyadarkagune sasi kakshyayaa hruthe kaarmukam thamovyaasa:

Multiply the moon's true distance in its orbit by 36, and divide by the Sun's true distance multiplied by 90 and divided

by 286, Subtract this result from 36, multiply by 120, divide by moon's true distance and get the arc of the resulting sine which is the angular diameter of the shadow: (Panchasiddhantika 10-1,2a). Corrected number given by modern astronomy is 284.4 instead of Varahamihira's value 286.

स्फुटशशिश्रवणेन विवर्जिता गगन पञ्चककुगुणिता कुभा ।
अपहृता च तया प्रभया भुवो भवति योजनबिम्बमगो: फलं ।।

Sphutasasisruanena vivarjithaa gagana panchakakugunitha kubhaa
apahruthaa cha thayaa prabhayaa bhuvo bhavathi
yoyanabimbamago: phalam

Length of the earth's shadow diminished by the correct distance of the moon from the centre of earth, then multiplied by 1050 and divided by itself, gives the diameter of the earth's shadow in yojanas (Sishyadhi vruddhi Tantra 5-7).

This is the method to find out the diameter of the earth's shadow in yojanas in the moon's orbit i.e at moon's distance.

True angular diameter of the Sun, the moon and the shadow: Angular diameter of the Sun, the moon and other planets have been discussed earlier. Vateswara has given this equation for the calculation of the true diameter of all those bodies which are connected with the eclipse:

रविचन्द्रतम: प्रविस्तरास्त्रिज्याघ्ना रविचन्द्रचन्द्रजै: विभजेत्स्फुटकर्णकै:
क्रमात् तद्बिम्बानि कलागतानि वै ।।

Ravichandrathama: pravisthara asthrijyaaghnaa
ravichandrachandrajai: vibhajethsphuta karnakai:
kramaath thadbimbaani kalagathaanivai

Severally multiply the diameters of the Sun, the moon and the shadow by the radius and divide the resulting products by the true distance of the Sun, the moon and the moon (again) respectively. Results are their diameters in terms of the minutes

of angle. (Vateswara Siddhanta 4-11).

Vateswara has given the exact equation and values for the diameter of shadow:

तत्वानि लिप्ता विकलास्तुरङ्गा रवेर्विधोरक्षदिशो जिनाख्याः ।
त्रिज्याहतास्ता मृदुकर्णभक्ताः भलान्तरं वा तमसः प्रमाणं ॥

Thathvaani lipthaa vikala sthurangaa raverudhoraksha
dhisoymaakhyaa: thriyyaahathaasthaa mrudukarnabhakthaa:
bhalaantharam vaa thamasa. pramaanam

Multiply 25′ 7″ by the radius and divide by the Sun's mandakarna (hypotenuse) and multiply 105′ 24″ the radius and divide by the moon's mandakarna. The difference of the results thus obtained are the measure of the diameter of shadow (Vateswara siddhanta 4-16)

Here the 105′ 24″ is obtained from the product of earth's diameter and radius divided by the moon's mean distance. (Where radius is taken as 3437.7 i.e angle in radians = 360 x 60/3.14). Similarly 25′ 7″ is obtained from the difference of the Sun's diameter and the earth's diameter divided by the Sun's mean distance. These are the same according to the modern astronomy also.

Comparison of positions of the Sun and the moon during lunar / solar eclipes:

अहर्दलाद्रात्रिदलावसाने यावत् कपालं कथयन्ति पूर्वं ।
ततो दिनार्धान्तमपूर्वमिन्दोर्भानोर्भवेतां ग्रहणोऽन्यथा ते ॥

Ahurdalaadraathridalaavasaanam yaavath kapaalam
kathayanthi poorvam thatho dinaardhaanthamapoorva
mindoorbhaanor bhavethaam grahanoanyathaa the

In a lunar eclipse the moon is said to be in the eastern hemisphere from midday till midnight. From midnight till midday it is said to be in the western hemisphere. In a solar

eclipse the contrary is the case. (Sishyadhi vruddhi Tantra 5-24)

पूर्वाशायां प्रग्रह:शीतरश्मे: पश्चान्मोक्षस्तिग्मगोरन्यथा तौ ।
क्षेपा: सर्वे व्यत्ययेन स्युरिन्दोर्यद्वद् भानोरागतास्तद्वदेव ।।

Poorvaasyaam pragraha: seetharasme: paschaanmoksha sthigma goranyathaa thou / kshepaa: sarvey vyathyayena syurindoryadvad bhaanoraagathaasthadvadeva

In a lunar eclipse contact takes place in the eastern portion of the disc of the moon and separation in the western portion. Contrary is true in solar eclipse (Sidhyadhi vruddhi Tantra 5-29)

स्वेभूच्छायामिन्दु: स्पृशत्यत: स्पृश्यते न पश्चोर्द्धं
भानुग्रहेऽर्कमिन्दु: प्राक् प्रग्रहणे रवेर्नात: ।।

Svebhoocchaayaamindu: sprusathyatham sprusyathe na paschorddham bhaanugrahearkamindu: praak pragrahanam ravernaatha:

In a lunar eclipse, the moon moving eastwards contacts the earth's shadow, therefore the first contact occurs at the eastern limit of the moon and so does not occur at the moon's western limb. In a solar eclipse the moon meets the Sun and therefore the first contact does not occur at the eastern limb of the Sun (Panchasiddhantika 6-14)

The moon's motion rate being thirteen times more than that of the Sun or the shadow, it moves eastward relative to the Sun or shadow and contact them at their western limb and its own eastern part.

प्रग्रहणान्ते धूम्र: खण्डग्रहणे शशी भवति कृष्ण:
सर्वग्रासे कपिल: सकृष्णताम्रस्तमोमध्ये ।।

Pragrahanaanthe dhoomra: khanda grahane sasee bhavathi krushna. sarvagrase kapila: sakrushnathaamra sthamomadhye

At the beginning and end of an eclipse, the moon is smoky, when half obscured it is black, when totally obscured it is tawny,

when inside the shadow, it is copper coloured (Aryabhteeya 4-46)

Similar explanations are given by Lallacharya

आद्यन्तयोर्बहुल धुम्रलवानुकारी खण्डग्रहे नियतमञ्जनपुञ्जवर्ण:
ग्रसे दलात् समधिकेऽरुणकृष्णवर्ण: सर्वग्रहेभवति शीतकर: पिशङ्ग: ।।

Aadyanthayobahula dhoomralavaanu kaaree khandagrahe nıyathamanjana punjavarna: graase dalaath samadhıke arunakrushna varna: sarvagrahe bhavathı seethakara. pisanga:

At the beginning and end of the eclipse the moon is of dense smoky colour. In a partial eclipse, it is always dark as a mass of collyrium, when the obscured portion is greater than half, it is dark red. When it is completely obscured it is tawny (Sishyadhi vruddhi Tantra 5-36)

Partial eclipse: However if the extent of the eclipsed portion of the Sun or moon is small due to the brightness of the Sun, the eclipse may not be seen. Under such conditions it is sometimes considered that there was no eclipse in observers' place.

द्वादश: सवितृमण्डलांशक पाटवेन महसो न दृश्यते खण्डितोऽपि
खलु षोडशांशक: स्वच्छतां विदधत: कलावत: ।।

Dvaadasa: savithrumandalaamsaka paatavena mahaso na drusyathe khandıthoapı khalu shodasaamsaka: svacchathaam vidadhatha. kalaavatha:

When 1/12 of the Sun is obscured the eclipse cannot be seen because of the Sun's brightness but owing to the moon's clearness even 1/16 part of it in lunar eclipse when eclipsed can be seen (Sidhyadhi vruddhi Tantra 6-17)

रविदेहस्याष्टमांशग्रहणमनोदेश्यमिति यावत्

Ravidehasyaashtamaamsagrahana manaadesyamithı yaavath

Some say that if the eclipsed portion of the Sun is less than 1/8, then the eclipse cannot be seen (Laghubhaskareeyabhashya by Sankaranarayana - 4-9)

Aryabhatta has given the same value for partial eclipse and the reason for that:

सूर्येन्दुपरिधियोगेऽर्काष्टमभागो भवत्यनादेश्यः ।
भानोर्भासुरभावात् स्वच्छतनुत्वाच्च शशिपरिधेः ।।

Sooryendu paridhiyogearkaashtama bhago bhavathyanaadesya:
bhaanor bhasurabhaavaath svacchathanuthvaachha sasiparidhe:

If the overlapping of the Sun's disc extends only less than 1/8, then eclipse need not be predicted. This is because of the brightness of the Sun which makes the eclipse invisible-from the earth- (Aryabhateeyam 4-47)

Bhattagovinda's opinion was different. It has been quoted by Sankaranarayana.

द्वादशभागादूनं ग्रहणं तैक्ष्ण्याद्रवेरनादेश्यम्। षोडशभागादिन्दोः
स्वच्छत्वादधिकमादेश्यम् ।।

Dvaadasa bhaagaadoonam grahanam thaikshnyaadraveranaadesyam
shodasa bhaagaadindo: svacchatvaadadhikamaadesyam

More than 1/12th for the Sun and more than 1/16th for the moon when eclipsed becomes clearly visible (Bhattagovind Khandakhadya sastram surygrahanam Xref Sankaranarayana Laghbhaskareeyabhashyam 4-9).

सूर्यमण्डले द्वादशांशो ग्रस्ताऽपि रश्मिप्रभावान्न लक्ष्यते
चन्द्रस्य शान्तरश्मित्वाच्चन्द्रमण्डले षोडशांशो ग्रस्तोऽपि लक्ष्यते ।।

Sooryamandale dvaadasaamse grasthaapi rasmi prabhaavaanna
lakshyathe chandrasya saantharasmithvaachhandra mandale
shodasaamso grasthaopi lakshyathe

Due to brightness of the Sun if $^1/_{12}$th of the Sun is eclipsed, the eclipse cannot be seen. Due to the mild rays of the moon even $^1/_{16}$th part can be seen. At noon even if it is $^1/_{8}$th portion of Sun is eclipsed it cannot be seen due to brightness (Mallikarjuna

Suri; commentary to Sishyadhi vruddhi Tantra 6-17)

तीक्ष्णांशुबिम्बवस्वंशलिप्तिकाकालसंयुत:
स्पर्शकालो भवेत्सत्यो भासुरत्वाद्विवस्वत: ॥

Theekshnaamsubimba vasuamsalipthikaakaalasamyutha:
sparsa kaalo bhavethsathyo bhaasurath vaadvivasvatha:

In the case of a solar eclipse on account of the brightness of the Sun, the time of the actual visibility of an eclipse is the time of the first contact plus the time corresponding to the minutes of arc that amounts to $^1/_8$the of the Sun's diameter. (Mahabhaskareeya 5-41).

Here this aspect of vision of the partial eclipse is extrapolated to the first contact too.

Graphical representation of eclipse: Graphical methods are supposed to be the modern approach of studying astronomy. But there are chapters, in books written by ancient Indian astronomers on this subject In fact graphical drawing of eclipse was the method adopted earlier by Indians. Here the methods on how to draw the path of obscuring bodies are described, Lallacharya says: 'Mark the three extremities of the latitudes - at the beginning, in the middle and in the end of an eclipse - draw two fish figures - one passing through the first two points and the other through the last two points - Draw two lines passing through the mouth and tail of each fish figure. With the point of intersection of these two lines to be the centre draw a circle passing through the three extremities of the latitudes. This is the path of the obscuring body. Then place the hypotenuse from the centre of the concentric circle just touching the path" This gives the methodology of drawing a graph of the eclipsing and the eclipsed body.

Eclipse and parallax : Aryabhatta has mentioned that due to the spherical shape of the earth, all the celestial bodies will be

seen at a different positon due to the influence of parallax. So the graphical presentation needs correction because of the parallax and aberration of visions. This subject has been discussed by Lallacharya and he advocates.

भूपृष्ठगतो द्रष्टा पूर्वनतं पूर्वमेव तिथ्यन्तात् पश्यति
समुच्छ्रितत्वाच्छशिना रविमण्डलं पिहितं ।
पश्यति यमकलकालात् परतोऽन्तरधीयते गतं नीचम् तेन प्राक्
पश्चिमयोः कुदलकलालम्बनमृणं स्वम् ।।

Bhooprushtagatho drashtaa poorvanatham poorvameva thithyanthaath pasyathi samucchri thathaacchasinaa ravimandalam pihitham/ pasyathi yamakalakaalaath paratho antharadheeyathe gatham neecham thena praak paschimasyo: kudalakalaa lambanamrunam svam

The observer on the surface of the earth sees the disc of the Sun obscured by the moon even before - the calculated time for conjuction - as he is elevated above the centre. This is so if the Sun is in the eastern hemisphere. But if the Sun is in the western hemisphere, he sees it after calculated time, when the Sun sets, i.e. it has disappeared below the horizon. So the parallax in longitude due to the radius of the earth is subtracted, from the calculated time of conjunction if the eclipse takes place in the eastern hemisphere and added if it takes place in the western hemisphere. (Sishyadhi vruddhi Tantra 16-14,25)

This statement is in agreement with the modern astronomical approach on the parallax during eclipse.

भूदलमध्यस्थस्यद्रष्टुर्भूपृष्ठगस्य वा दृष्टिः ।
स्वाभिमुखं याति समं न लम्बनं तेनमध्याह्ने ।।

Bhooodala madhyasthasyadrashturbhooprushtagasya vaa drushti: svaabhimukham yaathi samam na lambanam thena madhyaahne

The line joining the observer at centre of the earth and the

zenith coincides with the line joining the observer on the surface of the earth to the zenith. Thus there is no parallax at the mid day (Sishyadhi vruddhi Tantra 16-26)

From the above explanations it is very clear that much information on the astronomical phenomena taking place around us, were seriously studied by Indians. These studies were not philosophical nor were puranic explanations. But they used different types of instruments and calculated the details based fully on their observations. A sound application of mathematics can be seen at all instances in these calculations.

Knowledge of Stars

Ancient Indian astronomical knowledge did not confine to the studies of planets, the Sun and the moon. They had a good understanding of the star constellations. In Rig Veda, different star constellations are mentioned. Positions of the stars and a number of major stars in each constellations have been described in detail by Bhaskaracharya I. Latitudes and longitudes of these constellations are given accurately. In Laghubhaskareeyam, Bhaskaracharya I (528 AD) has been following positional data of the stars in latitudes and longitudes. The data are for the star constellation starting from Aswini onwards for the 27 sets (Laghubhaskareeya 8:1-4):

अष्यावष्यादश दिशो मनवोर्का द्वयोर्घन:

द्वाविंशतिश्च विश्वे च नव शक्रास्त्रयोदश

विश्वे विंशतिरेकोना द्वादशार्का दिनानि च

दिशो रसाश्च विश्वे च विश्वे सूर्या धृतिस्तथा

उद्रा: सूर्यास्त्रिसप्ताथ शैलेन्दुतिथयस्तथा

पूर्वपूर्वयुता ज्ञेया योगभागा यथोदिता:

उदग्दिशो/र्कभूतानि याम्ये पञ्चदिशोभवा:

उदग्रसास्तथा व्योमदक्षिणे मुनयोऽम्बरम्
उदगर्कास्तथा विश्वे दक्षिणे मुनयोऽश्विनौ
सौम्ये रसकृति सैका याम्ये सार्धास्तथाग्नयः
अब्धयो वसवः सार्धाः सप्तशैलास्ततः परम्।
उदक् त्रिंशत् कृतिः षण्णाम् याम्ये लिप्तास्त्रिषद्
उदगर्काश्च विश्वे च द्विरभ्यस्ता नभस्तथा
विक्षेपांशाः क्रमाद् दृष्यः पण्डितैर्वाजिभादितः ॥

Ashtaavashtaadasa diso manavoarkaa dvayorghana:
dvaavimsathischa visve cha nava sakrasthrayodasa
visve vimsathirekonaa dvaadasaarkaa dinaani cha
diso rasaascha visve cha visve soorya dhruthisthathaa
rudraa. sooryasthri sapthatha sailendu thithayasthathaa
poorva poorvayuthaa jneyaa yogabhagaa yathodithaa:
udagdisoarka bhoothaani yaamye panchadiso bhavaa.
udagrasaasthathaa vyomadakshine munayoambaram
udakarkaasthathaa visve dakshine munayoasvinow
soumye rasakruthi saikaa yamye saardhaasthathaagnaya:
abdhayo vasava: saardhaa: sapthasailaasthatha: param
udag thrimsath kruthi: shannaam yamye lipthaasthrishat
udagarkaascha visve cha dvirabhyasthaa nabhasthathaa
vikshepaamsaa: kramaad drushtaa: panditairvaajibhaaditha:

8, 18, 10, 14, 12, 8, 22, 13, 9, 14, 13, 13, 19, 12, 12, 15, 10, 6, 13, 13, 12, 18, 11, 12, 21, 17, and 15. Each of these numbers being increased by the sum of the preceding numbers is the longitudes of the 27 star constellations. To the longitudes of purvashada, sravana, mula, magha, dhanishta, bharani and uttarashada thus obtained, one should further add 30 min. of arc. All these values are in degrees of angle.

Latitudes of these stars are given by Bhaskaracharya I in

Laghubhaskareeya (8:6-9). In these lines, also data is given from the star Aswini for the 27 numbers, hence there will be repetitions of positional latitudes on either side of the equator as north and south.

North 10, 12, 5 south 5, 10, 11 north 6, 0 south 7, 0 north 12, 13, south 7, 2, north 37 south 1.5, 3, 4, 8.5, 7, 7 north 30, 36 south 18′ north 24, 26 and 0, are the latitudes of the stars. All these values are degree of the angle and only one value is in minutes.

Lallacharya in Sishyadhi vruddhi Tantra has given the following data for the position of the stars in polar longitudes:

गजाब्धयः शून्यकृता रसेषवः कृतेषवो युग्मशरा नखा द्रव्यगाः
खबाजिनोऽब्धिश्रुतयो गजाब्धयोरसाग्नयोऽब्धि श्रुतयो गजाद्रयः
रसर्तवो युग्मरसा यमाचला यमेषवोऽष्टाकृतवोऽब्धयोऽब्धयः
नवेन्दवो ऽनागभुवः खसागरा यमाब्धयस्तिग्मकराः कृताद्रयः ।।
क्रमेण सर्वाः खशशाङ्कताडिता भभोगलिप्ता मुनिभिः प्रकीर्तिता

Gajaabdhaya: soonyakruthaa rasesbava: krutheshavo yugmasaraa nakhaa dravyagaa: khabajino abdisruthayo gajaabdayorasaagnayoabdhi sruthayo gajaadraya: rasarthavo yugmarasaa yamaachalaa yameshavo ashtaa kruthavo abdhayoabdhaya: navendavo naagabhuva: khasaagaraa yamaabdhayasthigmakaraa: kruthaadaya: kramena sarvaa: khasasaankathaaddithaa bhabhogalipathaa munibhi: prakeerthithaa:

The position of the stars are said to be like this by the ancient sages. This is in the order from Aswini star onwards: 48′, 40′, 56′, 54′, 52′, 20′, 72′, 70′, 44′, 48′, 36′, 44′, 78′, 66′, 62′, 72′, 52′, 8′, 6′, 4′, 4′, 19′, 18′, 40′, 42′, 12′ and 74′, each multiplied by 10.

The corresponding values in degrees will be 8.8, 6.7, 9.3, 9, 8.7, 3.3, 12, 11 7, 7 3, 8, 6, 7.3, 13, 11, 10.3, 12, 8.7, 1.3, 1, 0.7, 0.7, 3.2, 3, 6.7, 7, 2, 12 3 These values are given in angular dimensions.

The total of these angles is equal to 360 degrees. Thus the knowledge that the celestial sphere around the earth was divided exactly and accurately among these star constellations, existed clearly in olden times.

दशलोचनभूमय: शरा विषय व्योमभुव: पिनाकिन:
षडथाम्बरमद्रयो/म्बरं स्वयो रामभुवो गजा यमौ
नगाग्नयो/र्धेन विवर्जितं द्वयं त्रयो/ब्धयो/र्धेन युता भुजङ्गमा:
त्रिभागयुक्ता विषय शिलीशुखा: खवह्नय: षट्कगुणा लवा: स्मृता:
ततस्त्रिभागो/थ जिना: षडश्विनो नभश्च भागस्य मितिर्जिनाङ्गुला:

Dasalochana bhoomaya: saraa vishaya vyomabhuva:
pinaakina shadathaambaramadrayo ambaram
suayo raamabhuvo gajaa yamow nagaagnayo ardhena vivarjitham dwayam
thrayoabdayoardhena yuthaa bhujangamaa: thribhaagayukthaa
vishaya sileesukhaa: thathasthribhaagoatha jinaa: shadasvino
nabhascha bhaagasya mithirjanaangulaa:

The polar latitudes of the stars from Aswini measured from the ends of their respective declination on the ecliptic corresponding to their polar longitudes are 10°, 12°,5°, 5°, 10°, 11°, 6°, 0°, 7°, 0°, 12°, 13°, 8°, 2°, 37°, 1° 30′, 3°, 4°, 8° 30′, 5° 20′, 5°, 30°, 36°, 20′, 24°, 26°, 0°, (1° = 24 angulas). (Sishyadhi Vruddhi Tantra (11-5-7)

The position of stars, in relation with the equatiorial line, has been described in Sishyadhi vruddhi Tantra (11-9, 10):

रुद्रसार्प्यपुरुहूतभवेशब्राह्मभूलकरमित्रभचित्रा:
वारुणप्य मृगशीर्षविशाखा भान्यमूनि खलु याम्यशराणि ॥
पुष्यो/थ पौष्णं पितृदैवतं च क्रान्त्यग्रकाण्युत्तरतो/पराणि
वैश्वान्त्यपाद: श्रवणे चतस्रो नाड्यो भभोगो/भिजिदत्र दृष्ट: ॥

Rudrasaarpyapuruhootha bhavesa braahma moolakara
mithrabhachithraa: vaarunapya mrugaseersha visaakha

bhaanyamooni khalu yaamya saraani pushyoatha poushnam
pithrudaivatham cha kraanthyagra kaanyuthbharatho aparaani
vaaruvaanthyapaada: swaane chathasro naadyo bhabhogaabhi prathama drushtaa:

The latitudes of ardra, aslesha, jyesta, utharashada, poorvashada, rohini, mula, hasta, anuradha, citra, satabhishak, mrgasira, visakha are to the south. The latitudes of pushya, revati, and magha are 0° i.e. they are seen at the end of their respective declinations. The remaining stars have northern latitude.

On the conjuction of the planets Lallacharya gives this information:

ध्रुवकादधिके युतिर्गता भवितोने विपरीतगेऽन्यथा ।
Dhruvakaadhike yuthirgathaa bhavithone vipareethageanyathaa

If the true longitude of the planet is greater than the polar longitude of the star, its conjuction has taken place, if less it will take place. When planets retrograde the contrary is true (Sishyadhi vruddhi Tantra 11-4)

Commets

Comets were also mentioned in some ancient Indian works. A series of superstitions have been associated with the comets on the basis of puranic stories. However the name given in Sanskrit dhoomaketu has a sound scientific background associated with the meaning: having a tail of dust/smoke. Significant information was known about the comets. Bruhatsamhita of Varahamihira says thus [734]. "Some people say that the number of comets is 100, others say it is 1000, but sage Narada says that the same comet may appear in different ways" (Bruhatsamhita 11-5).

These lines are given in the Indian Journal of the History of Sciences. "The maximum time period is 36 years and average time 24 years and the minimum time 13 years for the appearing of comets" (Bruhatsamhita 21-42).

All these astronomical information could be gathered with the excellent brain work. They absorbed only the knowledge from all over the world. They also delivered the information all over the world. It is our proud privilege to look further deep into the astronomical heritage of India.

CHAPTER - VII: ANCIENT INDIAN CONTRIBUTIONS IN METALS AND ALLOYS

It has of great importance and relevance to discuss the modern concepts applied in ancient Indian science, related to metals and alloys. Remarkable evidences have been obtained from the archaeological studies, on the science of metals, described in Sanskrit literature of ancient India. For information on metals and alloys one can go through the authoritative archaeological findings. The most significant base for collecting ancient Indian data on the age of the technology is the C^{14} dating technique. Through this technique, any sample can be accurately dated. Hence the dates of production of the old metal samples can be easily found out.

Technological capability in the past.

More than a thousand ancient metallic samples of many millennia old were collected from various sites and subjected to in-depth studies in India and abroad. A variety of Sanskrit books also pour information on this subject, substantiating the knowledge demonstrated in Sanskrit literature with the archaeological evidences. Vedas are the oldest sources of information which are given indirectly. The direct sources are the good number of books in Sanskrit on Chemistry and Ayurveda discussing the metallurgical subject. Susrutha samhita and Charaka samhita gives important information on various

types of metalic surgical instruments used during the period. These two books were written in the first part of the first millennia BC. Artha sastra of Kautilya stands unique, in carrying remarkable information on metals, ores, alloys, and their management in this country. Perhaps no other text gives this much integrated information as the Kautilya s Arthasastra, which was written in the third century, BC. From the available books on chemistry Nagarjuna's Rasaratnakara stands first, which is dated 200 AD. It appears that another Buddhist monk, Nagarjuna has rewritten this book in the 6th Century AD. Bruhatsamhita of Varahamihira written in the early part of the sixth century carries lot of information on this subject. Ashtangahrudaya of Vagbhata belongs to the 8th century A.D Rasahrudaya and Rasarnava, of Govindabhatta, Rasarnavakalpa, Rasendra choodamani of Somadeva, etc., belong to the period between 9th and 11th century. Rasaprakasasudhakara, Rasakalpa and Rasaratnasamucchaya were written before the 13th century. In fact the study of metals and their products come under the Rasachikitsa, which is considered a part of the Ayurvedic systems. Hence all the Ayurvedic books contain some information on the metals. However, there exist a few books dealing only with the subject of Lohatantra i.e the science of metals.

The Indian capability in metals are directly available from the metal works demonstrated in ancient buildings and temples. These observations are to be correlated with the knowledge that existed in Sanskrit literature. It goes without saying that unless the metallurgical and the alloy making process were known, those metals could not have been mentioned in the ancient books. In Rig Veda (1.122.14) mention is made on a golden ear ring as *hiranyakarnam manigreevam*. A golden necklace is mentioned (1.33.8) as *hiranyayena manina srumbhamaana*. Thus gold as a precious metal was known to the Indians even during (or before) the period of Rig Veda. Sukla Yajurveda (Sukla yajurvedeeya

Vajasaneyee Madhayandina Samhita, 8:13) gives the list of a variety of materials present on the earth in which the metals like iron, gold, silver, copper, lead, and tin are also included.

हिरण्यं च मे/यस्चमे सीसं चमे त्रपुश्चमे श्यामं च मे लोहं च मे ।

Hiranyam cha meayaschame seesam chame thrapuschame
syaaamam cha me loham cha me

Names mentioned in this texts are syama, hiranya, mehaja, seesa and trapu. Each of these metal has different physical and chemical characterstics and need different types of extraction processes to get them out of their ores. No superfluous knowledge on the ore can give such names for the metals, unless they were produced. All these metals can be obtained by complex processes. Other than the above mentioned stanzas, occasional mention of these metals can be seen in the Yajur Vedic texts. The ores and minerals of metals mentioned in the Vedas are seen in the archaeological location of the Indus Valley civilisation which are the referred Vedic sites. Atharva Veda also carries information on the metals. An interesting stanza (Atharva Veda 11.8.7-8) is the comparison of the colour of the universal power with that of metals:

श्याममय अस्यमासानि लोहितमस्य लोहितं त्रपु भस्म हरितं मर्ण:
पुष्करमस्य गन्ध:

Syaamamaya asyamaamsaani lohithamasya lohitham thrapu
bhasma haritham varna: pushkaramasya gandha:

His flesh has the colour of syama (iron), blood has the colour of loha (copper), totally he has the colour of tin and has the smell of lead. This gives us the message that the metals with that level of purity to be indentified with the exact colour were available during the period of Atharva Veda.

Chandogya Upanishad which is one of the earliest

Upanishads, chronologically coming at par with the Yajurveda period, mention the philosophical approach of knowledge on everything, by citing an example of a metal instrument. This is specifically quoted to highlight its importance as a concept followed in presenting the subject matter in this text, also

नखकृन्तनेन सर्वकार्ष्णायसं विज्ञातं ...... कृष्णायसं इत्येव सत्यम् ।

Nakhakrunthanena sarvakaarshnaayasam vijnaatham
.... krushnaayasam ithyeva sathyam

By knowing the nail cutter all things made of iron become known.......... iron as such is the reality. (Chandogya Upanishad 6.1.6):

Here, the word Krishnayasm is used for iron. This statement throws light on the perfected iron extraction process in the metallurgical studies. Exactly the same words are repeated in the Upanishad to refer to copper as lohamani. (Chandogya Upanishad 6.1.5). It also tells the philosophical approach in literature, even though only a little is given, a lot of information should have to be gathered from it. It is particularly true in case of metallurgical knowledge. As in-depth knowledge of the metallurgical alloying is indirectly presented in the Upanishad (4.17.7) "One would join gold with the help of borax, silver with gold, tin with silver, lead with tin, copper with the help of lead and timber with copper and leather".

तद्यथा लवणेन सुवर्णं संदध्यात्सुवर्णेन रजतं रजतेन त्रपु त्रपुणा
सीसं सीसेन लोहं लोहेन दारु दारु चर्मणा

Thadyathaa lavanena suvarnam sandadhyaathsuvarnena
rajatham rajathena thrapu thrapunaa seesam seesena loham
lohena daaru daaru charmanaa

This is perhaps the best quotable stanza from ancient books on alloying of metals. This is a technique, adopted even now for

reducing the melting point of the metals to be alloyed.

Technological details of metals and alloys can also be discussed with the support of archaeological observations. One of the findings which exist even now is the standing 250 feet, monument in the Singbum copper mine and the 600 feet deep vertical shaft in Hutti gold mines. These two indicate the highest degree of technical competence in ancient mines in India during the Vedic period. Further descriptions are given by Dr. Mukherjee in the Indian Journal of History of science [76].

Ancient Indian Mines: earliest mention of mines appears to be made by Kautilya in Arthasastra Superintendent of the mines was called Akaaradhaayksha (Arthasastra 2.12.30)

आकाराध्यक्षः शुल्भधातुशास्त्रपाकमणिरागज्ञस्तज्ज्ञसखो वा
तज्जातकर्म करोपकरणसंपन्नः किट्टमूषांगारभस्मलिंगं वाकरं
भूतपूर्वमभूतपूर्वं वा भूमिप्रस्तररसधातु मत्यर्थवर्ण्णगौरवमुग्रगन्धरसं परीक्षेत ।

Aakaaraadhyaksha: sulbadhathu saasthrapaakamaniraaga jiynasthajjajnasakho vaa thajjaatha karma karopakarana sampanna: kittamooshangaarabhasmalingam vaakaram bhoothapoorvamabhootha poorvam vaa bhoomi prasthara rasa dhatumathyartha varnna gouravu mugragandha rasam pareekshetha

The director of mines is responsible for the ores, minerals, chemicals, etc. He should have the knowledge of these things and he is responsible for the examination and utilisation of three types of ores. Bhoomi-prastara-rasa dhatus (ores of three types). He has to know the quality of ores by means of colour, smell taste, acidic-alkaline and -textural tests.

The metals obtained from mines are said to be gold, silver etc., and diamonds (Arthasastera 2.6.4). It is also said that the treasury has its source in mines, from treasury, the army comes into being. With the treasury and the army, land is obtained.

With the treasury as its ornament is, the mines. (2.12.37). Twelve kinds of metals obtained from the mines are mentioned in Arthasastra (2.12 23 and 35, 36)

In Arthasastra, the melting process is given as dravana (3 3.27). Melting of the metals was also known as Vipalana. and the term is particularly used for iron and copper. Solidification of the metal is described as mruthi. Heating is the most important processing in alloying metals. It is thus said:

नातप्तं लोहं लोहे न सन्धत्ते

Naathaptham loham lohe na sandhatthe

Without heating metals cannot be alloyed.

C_{14} carbon studies conducted by the metallurgists have shown that ancient mines used for the production of silver, tin, copper, lead and zinc were seen in many locations. A few among the most ancient are mentioned here. Some of the metallic samples obtained from the sites are two thousand to three thousand years older than the periods given below. Dates given below are the most active period of the production of metals from these mines.

Rajapura, Dariba, Udaipur in Rajastan	1300 BC
Hatti in Karnataka	1000 BC
Rampura, Agucha	700 BC
Zawarmala and Ambamata in Rajastan	500 BC

Iron was extracted from the following mines.

Komaranahalli and Tadanahalli in Karnataka, 1300 BC

Atranjikhera	1200 BC
Pandu Rajar Dhibi in Bengal	1300 BC
Alamgirpur in Rajastan	1000 BC
Varnasi	1000 BC

Descriptions of Mettallic Ores and Minerals: Ores and minerals are the natural metallic compounds present in the earth. There are a variety of such compounds from which the respective metals can be extracted. Arthasastra is the most authentic ancient text book describing the ores of metals. Arthasastra (2.12.30):

पीतकास्ताम्रपीतकाभूमिप्रस्तरधातवो भिन्ना नीलराजीमन्तो
मुद्गमाषकृसरवर्णा वा दधिभिन्दुपिण्डचित्राहरिद्राहरीतकी
पद्मपत्रशैवलयकृत् प्लीहानवद्यवर्णा भिन्नाश्चुञ्जुवालुका
लेखाभिन्दु स्वस्तिकवन्तः सगुलिका अर्चिष्मन्तस्ताप्यमाना न भिद्यन्ते
बहुफेनधूमाश्च सुवर्णधातवः प्रतीवापार्थास्ताम्ररूप्य वेधनाः

Peethakaasthaamra peethakaa bhoomiprastharadhathavo bhinna neelaraajimantho mudga maasha krusara varnaa vaa dadhi bhindu pinda chithraa hari draahareethakee padmapathra saivalayakruth pleehaanavadyavarnna bhinnaaschujnajuvalukaa lekhaabindu svasthikavantha: sagulikaarchishmanthasthaapya maanaa na bhidyanthebahuphena dhumaascha suvarnadhathava: pratheevaapaarthaa sthaamraroopya vedhanaa:

The colour of different ores can be yellow, mixed yellowish red, when cut, it can be bluish colour of green gram, black gram, curd, turmeric, terminalia seeds, liver of animal, spleen sand, jasmine bud, seed of neem. Some of the ores when burnt remains the same and Surf is formed in some cases. These descriptions agree well with the information available on minerals and ores of the metals.

Description of silver ores:

शङ्खकर्पूरस्फटिकनवनीतकपोतपारावत विमलकमयूरग्रीवावर्णाः
सस्यक् गोमेदकगुडमत्स्यण्डिकवर्णा कोविदारपद्मपाटलीकलाय
क्षौमातसीपुष्पवर्णाः ससीसाः सो जनाविस्रा भिन्नाः श्वेताभाः कृष्णाः

कृष्णाभा: श्वेता: सर्वे वा लेखाबिन्दुचित्रा मृद्वोध्माय मानान
स्फुटन्तिबहुफेनधूमाश्च रुप्यधातव: सर्वधातूनां गौरववृद्धौ सत्ववृद्धि:

Sankakarpoora sphatikanavaneetha kapotha paaraavatha vimalakamayooragreevavarnaa: samyak gomedaka guddamathsyaandika varnaa kovidaarapadma paataleekalaaya kshoumaathasee pushpavarnaa saseesa: so yanaavistaa bhinna: sethaabhaa. krishnaa: krishnaabhaa: svethaa: sarve vaa lekhabindu chithraa mrudvodhmaaya manaana sphutanithi bahuphena dhoomaascha roopyadhaathava: sarvadhaathoonaam gouravavruddhow sathvavruddhi:

Native silver ores are of 18 types. They are classified on the basis of colours: colour of conch shell, camphor, pearl, jewel, jaggery, lotus flower, etc. Some times they get mixed with lead. Some are white outside and black inside. Smoke comes out when burnt. In all the minerals the density increases with the metal content in them These observations agree well with the qualities noted for silver ores available from different part of North India.

Description of copper ore: Copper ore is explained in Arthasastra (2 12:30)

भारिक: स्निग्धो मृदुश्च प्रस्तरधातुर्भूमिभागो वा
पिङ्गलो हरित: पाटलो लोहितो वा ताम्रधातु:

Bhaarika: snigdho mruduscha prastharadhaathur bhoomibhaago vaa pingalo haritha: paatalo lohitho vaa thaamradhaathu:

This can be translated as Heavy, tawny, green (Chalcopyrite ore) dark blue (malachite ore) yellowish tint (azurite) pale red or red (native coper) are the ores (dhatus) of copper. The explanation given in Arthasastra agree well with the characterstics of the ores of copper given in bracket.

काकमेचक: कपोतरोचना वर्ण: श्वेत राजिनधो वा विस्र: सीसधातु:

Kaakamechaka: kapotharochanaa varna: svetha raajinidho vaa visra: seesadhaathu

Lead ores are explained by Kautilya (2.12.30). It is greyish black like kaka mechaka, (galena ore), yellow like pigeon bile (gossam ore), etc. The characterstics agree with galena and gossam ore of lead.

Description of Tin ore: Tine ore is as grey saline or like brown burnt earth (cassiterite) (Arthasasthra (2.12.30)

ऊषरकर्बुर पक्वलोष्टवर्णो वा त्रपुधातुः

Usharakarbura padvaloshtavarno vaa thrapudrathu:

Description of Iron Ore: Iron ore is explained (Arthasasthra 2.12.30) thus:

सुरुम्बः पाण्डुरोहितः सिन्दुवारपुष्पवर्णो वा तीक्ष्णधातुः
काकाण्डभुजपत्रवर्णो वा वैकृन्तकधातुः

Surumba paandurohitha: sinduvaarapushpavarno vaa theekshna dhaathu: kakaanda bhujapathravarno vaa vaikrunthaka dhaathu:

Greasy stone, pale red, colour of orange limonite or Sindudrava flower (Hematite). The ore which has the colour of crow egg or birch leaf is vaikruntaka ore (magnetite).

The qualities attributes to these ores are identified and found correct. On the-technology aspects also Chanakya has given descriptions. In Arthasastra he has mentioned that the Director of metals (Lohaddhyaksha) should establish factories for the production of metals and alloys like copper, lead, tin, vaikruntaka, arakuta, brass and steel, bronze, tala (bell metal) and loha from the corresponding metal ores. All the business related to metals also should be undertaken under his supervision (Arthasastra 2.12.30)

लोहाध्यक्षः ताम्रसीसत्रपुवैकृन्तकार कूटवृत्तकंसताल
लोहकर्मान्तान् कारयेत् लोहभाण्डव्यवहारं च

Lohaadhyaksha: thaamra seesathrapu vakrunthakaara kootavrutthakamsathaala loha karmaanthaan kaarayeth lohabhaanda vyavahaaram cha

An integrated knowledge of the mines, ores and the metal processing that existed in the time of Kautilya, i.e 350 years before Christ, is reflected)

Impurities in Ores: Other than the specific metallic compounds present in the ores, there can be a variety of attached impurities too. Mention of these impurities is also made in the Arthasastra text, "thus some of the impurities are attached firmly with the ore. They can have intense smell and may be alkaline in nature. These impurities are to be mixed with other things and burnt off for removal". In modern metallurgy the organic matter present in the ores is burnt and inorganic impurities are converted into slag and removed from molten metal.

Furnaces and kilns: Different varieties of furnaces and kilns were used in earlier days for the extraction of metals from their ores. A furnace or kiln is defined according to the process taking place in the furnace. In Sanskrit the furnace/kiln is known as Musha, which is defined as follows:

मुष्णाति दोषान् मूषेयान् सा मूषेति

Mushnaathi doshaan moosheyaan saa mooshethi

The vessel which removes or destroys the impurities is known as Musha.

Furnaces are made of special types of sand as followed in modern technology. The quality of the sand used for making furnaces has been defined as follows:

मृत्तिका पाण्डुरस्थूल शर्करा शोणपाण्डुर चिराध्मानसहासाहि
मूषार्थमतिशह्यते ।।

Mrutthikaa paandurasthoola sarkaraa sonapandura chiraadmaana sahaasaahee mooshaartha mathisahyathe

Yellowish white and heavy sand or reddish white sand that can withstand high temperature for a long time, is the best for the manufacture of Mushas/kilns and furnaces. Different varities of furnaces used for specific purposes are named in Rasaratna samuchaya:

वज्र योगवज्रद्रावणिगारवरवर्णरुप्यविडवृन्ताकं गेस्तनि
मल्लपक्वगोलमहामाण्डूकं मूशलमूषा ..... ।।

Varja-yoga-vajradravani-gara-vara-varna-roopya-vida vruntaka-gostani-malla-pakwa-gola-maha-maanduka-musala are the common furnaceskilns

For extraction, purification and alloy making, suitable furnaces and kilns from among this list are used. Furnaces mentioned here are of different sizes, shapes and for different purposes.

The temperature for extraction of metal is attained according to the nature of the metals and ores. The process is sometimes called Kupeepaka vidya. And the process adopted for getting different levels of heat is by using putas which are generally cubical in shape. All these putas are able to provide an average temperature of 750° - 900°C. The duration of maintaining the temperature and the dimensions of these putas are given below·

Mahagajaputa furnace	: 36 width x depth.	Duration	150 min
Gajaputa furnace	: 22 ½ "	"	100 min
Varahaputa	: 16 "	"	50 min
Kukkutaputa	: 9 "	"	5 min
Kapota puta	: earth surface	"	Low temperature

The above types of putas were made using cubical arrangement of cow dung cake. For example in mahagajaputa, 2000 cow dung cakes were arranged and for other putas 1000, 800, 40 and 8 cakes respectively were used. The number of cakes used depend upon the final temperature required and the duration upto which the temperature are to be maintained. And this in turn depends on the metal which is to be processed. Every puta has a definite specificaiton to follow. This definitely is the modern approach followed in metal technology. The above temperature values attainable have been recently reported by experimenting with modern instruments for each putas, based on the information given in Rasaratna samuchaya.

Interestingly in the above mentioned archaeological sites many furnaces/kilns, of measurements ranging from one ft high to 7ft high and internal thickness upto 1.5 ft were seen. These kilns had been in use during the periods from 2000 BC onwards.

Qualification of pure metals: Each metals has specific colour, texture and nature. But while producing these metals, the purity was judged by following general characteristics, which were also known to ancient Indians.

The qualification of pure metal is defined correctly in Rasarnava (52-55)

न विस्फुलिंगा न च बुद्बुदाश्च यदा न रेख पटले न शब्दः ।
मूषागतं रत्नसमं स्थिरश्च तदा विशुद्धम् प्रवदन्ति लोहं ।।

Na visphulingaa na cha budhbudaascha yadaa na rekha na sabda:
mooshaagatham ratnasamam sthirascha thadaa visuddham pravadanthi loham

Pure metal is that which when melted in crucible does not give sparks nor bubbles, nor spurts, nor emits any sound nor

shows any lines on the surface, but is tranquil like gem and this pure metal flow out, from furnace.

This definition stands correct, because all the above qualification are possible only if impurities are absent in the molten metal, at that temperature.

Use of flux to remove impurtiry as slag: Metals and impurities are difficult to melt directly during the metallurgical process. Flux, which is a foreign material, is added to remove the impurities as slag. This process was known earlier.

दुर्द्राव अखिल लोहादेः द्रावणाय गणो मतः

Durdraava akhila lohade: dravanaaya ganomathai:

It is mentioned that, to aid melting of otherwise difficult to melt metals / impurities, lower fusing materials are added (Rasaratna samucchaya 10.95)

A variety of fluxes have been used to convert impurities into slags. These slags were obtained from almost all the mine sites where lead, tin, copper and iron were extracted. Their period of production has also been estimated. One such archaeological site is the Rajghat copper mines. Large amount of slag was present there, which contained 5 4% calcium oxide. The calcium oxide was specifically brought from far away places to this location for the specific purpose. It is not available nearby places. The technology of use of calcium oxide to remove the impurity was the same as that followed in modern processes. Calcium oxide is used as flux to remove the silicon dioxide by converting into calcium silicate. Once, the slag is discarded major portion of the impurities from the metal is removed. This gives reasonably pure metal, which can be further purified or alloyed. The quality of the technology adopted in the metallurgical process can be appreciated only if the percentage purity of the metal obtained is compared.

Purity level of ancient Indian metals : A few examples.

copper	-	Nalanda	97.9%
copper	-	Mohan jodara	97.1%
copper	-	Atranjikhera	97.3%
silver	-	Mohan jodaro	94.5%
lead	-	Mohan jodaro	99.7%
copper in alloy	-	Harappa	98.8%
nickel in copper alloy	-	Taxila	21.0%
lead	-	Lothal	99.5%
copper	-	Harappa	99.0%
bronze	-	Taxila	85% copper/9.8%tin
brass	-	Taxila	55.4% copper/34.3% zinc

The archaeological sites noted above were active metallurgical centres/cites between 300 BC to 3000 BC. Majority of these centres existed around 3000 BC and period Lothal was 2200 BC.

Purity of the above mentioned metal samples are very high. Lead with 99.7% purity could be produced in Mohan jodaro. Similarly other metals, from this one can imagine the technological capability existed.

Thus archaeological evidences of a variety of kilns, knowledge on production of high temperature, use of flux, absolute quality of pure metal, are all in full agreement with what is given in the Sanskrit literaure on the science of metals and ores.

Corrosion of metals : Degradation of metals by way of atmospheric reactions with oxygen, moisture, acidic or alkaline materials are natural phenomena. The knowledge of this subject was existing in India. This is generally termed as corrosion study, in modern science. This is mentioned in Rasarnava (7.89-90)

सुवर्णं रजतं ताम्रतीक्ष्णवंग भुजंगमाः
लोहकं षड्विधम् तच्च यथापूर्वं तदक्षयं

Suvarnam rajatham thaamra theekshna vanga bhujangamaa;
lohakam shadvidham thachha yathaapoorvam thadakshayam

Gold, silver, copper, iron, lead and tin are the six types of metals which undergo self corrosion at a slower rate in the reverse order of this arrangement.

Le gold is the least corroding and tin the fastest corroding among the six metals mentioned here. Corroded impurities formed on the surface of metals such as oxides, hydroxides, carbonates, etc., are removed by washing with acidic or alkaline solutions. Present day application is also in line with the above knowledge. Yajnavalkhya smruti (Acharadhyaya 190(8) refers to the cleaning of the metals.

त्रपुसीसकताम्राणां क्षाराम्लोदक वारिभिः भस्मादि
कांस्यलोहानां शुद्धि प्रावोद्रवस्य च ।।

Threpuseesaka thaamraanaam kshaaramlodaka vaaribhi;
bhasmaadi kamsyalohaanaam suddhi praavodravasya cha

Tin, lead, copper, may be cleaned with alkali and acids. Iron, bronze and copper alloys are cleaned with ash and water.... The use of acids and alkalies readily decomposes the corroded impurity from the surface of the metals and cleanse the metals.

Alloy making:

The Indian authority on the production of the alloys has been well appreicated from time immemorial. Living examples are available throughout India, in the buildings and temples where a variety of metallic alloy have been utilised, like bronze and other alloy. Ashoka is said to have installed 85000 statues of which 30% are made of metals. In South India, a variety of

Panchaloha idols were made, which have an unusual composition of a variety of metals [79].

Arthasastra says that the coins are manufactured using different metal alloys. The nature of alloys in coins are described in lines 2,12:30 of Arthasastra

लक्षणाध्यक्षः चतुर्भागताम्रं रूप्यरूपं तीक्ष्णत्रपुसीसाञ्जनानामन्यतमाषबीजयुक्तं कारयेत् । पणं, अर्धपणं, पादमष्टभागमिति ॥

Lakshanaadhyakshaa: chathurbhaaga thaamram roopyaroopam theekshna thrapuseesaa jnaanaanaamanyatha masha beejayuktham kaarayeth, panam ardhapanam paadamashtabhaagamithi

The Director of coins should know how to make four types of coins. i.e one pana, half a pana, one fourth and one eighth of a pana using copper, silver, lead, iron and if required other metals.

Further, Kautilya explains the alloying of metals to make the coins and their denominations (Arthasastra 2:12:30)

पादाजीवं ताम्ररूपं माषकमर्धमाषकं काकणीमर्धकाकणीमिति ॥

Paadaajeevam thaamraroopam mashakamardha maashakam kaakaneemardhakaakaneemithi

The above statement when analysed using the explanations given in the commentary on the metallic compositions gives this meaning. Padajeeva type of copper coin contains 4 parts of silver and 11 parts of copper and 1 part of any metal like iron, tin, lead or antimony. This coin is known as Mashakam. Half of this composition is known as ardha mashakam, One fourth of this gives kakani, one eighth of this is ardha kakani.

This gives proof good on knowledge on alloy making process for the manufacture of coins, which is one of the sophisticated techniques adopted for getting uniform, size, shape, weight and quality coins

Specific metallic alloys

Bronze: Bronze is one of the most common and important alloys used in India. Archaeological information available on the bronze is plenty Bronze and brass are the two alloys obtained from almost all the excavated sites. This shows that, preparation of alloys was very familiar throughout this continent. Vedas also give the descriptions of this alloy. The most common alloys used in temples of South India were bronze and brass as statues, vessels or decorated backgrounds of the structures. Specific descriptions on bronze and brass can be seen in Panini's Astaddhyayee (8.2.3.1) in which the bronze vessels are discussed:

बहुक्षीरघृतमोदनम् कांस्यपात्र्यं भुञ्जीरन्निति

Bahuksheeraghrutha modanam kaamsyapaathryam bhunjeerannithi

Brass and bronze vessels can be used for storing ghee, milk, etc.

Panini was a contemporary scholar of the ruler Pushyamitra Sunga (187 BC). This line gives the information on the use of copper alloy. Earlier to Panini, the author of Arthasastra, Kautilya has described bronze while commenting on the duties of the lohaddhyaksha, which is mentioned earlier (2.12 30). Rasaratna samucchaya (5.205) gives the composition of one type of bronze.

अष्टभागेन ताम्रेण द्विभाग कुटिलेन च विद्रुतेन भवेत् कांस्यम्

Ashtabhagena thamrena dvibhaaga kutilenacha
vidruthena bhaveth kaamsyam

Eight part by weight of copper and two part by weight of tin gives the best bronze. Archaeological observation shows that bronze obtained from Lothal has 11-12% tin in it. A variety of bronze tools obtained from Mohanjo daro has copper content ranging 80 - 90% correspondingly, the remaining part is tin.

Brass : As in the case of bronze, the explanations on brass in

Sanskrit literature and also the nature of ancient brass samples give ample proof that the metallurgical knowledge of this alloy was millennia older than even Christian era. Zinc is also called suvarnakara because it converts copper into gold like alloy, which is brass. Earlier quotations given from Arthasastra carries information on brass. Brass was made in India by directly alloying the copper with zinc and also by alloying copper with zinc ores.

Brass alloy making observation is thus described. (Rasaratnakara 3)

किमत्रचित्रं रसको रसेन ..... क्रमेण कृत्वाम्बुधरेण रंजित:
करोति शुल्वं त्रिपुटेन काञ्चनं

Kimathra chithram rasako rasena kramena kruthvaambudharena ranjitha.karothi sulvam thriputena kaanchanam

What wonder is that calamine (zinc ore) roasted thrice with copper convert the latter into gold (actually brass)

The procedure explained here is the indirect alloying of copper with zinc ore. The decomposed zinc ore and separated metal zinc, directly but slowly alloys with copper and brass is formed. Modern studies have shown that the maximum content of zinc (from calamine) that can alloy with copper under this condition is 28% (i.e from the zinc ore). Ancient brass materials have shown that the majority of the samples obtained, contained less than 28% of zinc. This may be due to the fact that, those brass samples might have been prepared from zinc ore and copper metal. Alloying the zinc directly with copper has also been discussed in Rasarnava (7.34-38)

सत्वं कुटिलसंकाशं करोति शुल्वं त्रिपुटेन काञ्चनं

Satvam kutilasankaasam karoti subram thriputena kaanchanam

Zinc, a metal like tin converts copper into gold.

Here the use of the term gold is for brass. Panini in

Ashtaddhyayee has mentioned Suvarnakara for the tin/zinc (5.1.30) while discussing the coins made of copper or tin by alloyings with zinc.

Brass samples from Lothal had the composition of 6.04% zinc and 70% copper. This brass belonged to the period of 2200 BC. The earliest brass piece containing more than 28% zinc was obtained from Taxila, the period of which is 4th century BC. This brass was prepared by directly alloying copper and zinc metal instead of zinc ore (calamine) become more than 28% zinc was present in it.

Rasaratna samuchhaya (5.191-193) gives description on brass

रीतिका काकतुण्डी च द्विविधं पित्तले भवेत् ।
सन्तप्ता कांजिके क्षिप्ता ताम्राभा रीतिका मता ।।
एवं या जायतेकृष्णा काकतुण्डीति सा मता ।
गुर्वीमृद्वि च पीताभा सरंगी ताडनक्षमा ।।

Reethikaa kaakathundee cha dvividham pitthalam bhaveth
Santhapthaa kaanchike kshipthaa thamraabhaa reethikaa mathaa
evam yaa jaayathekrishnaa kaakathudeethi saa mathaa
gurveemruddhi cha peethaabhaa sarangee thaadanakshamaa

Brass is of two kinds reetika and kakatundi. The former when heated and plunged into sour gruel turns into copper coloured and the latter one turns black. The former is heavy, soft, yellow, resistant to hammering, brilliant and smooth.

This explanation stands as far as the qualification of brass is concerned. The brass which contains less than 28% zinc has the above said property.

This brass according to modern terms is alpha brass. Whereas the second one contains more zinc in it. It should have different properties from that of alpha. Mention of crow colour

(Kakatundi) can be due to the blackening of brass containing a traces lead present in zinc.

These descriptions throw light on the highly scientific approach followed in alloy making. The observation made on the post processing of brass by treating with sour gruel is a quality analyses parameter of brass.

Bell metal : Sound of the bell has been sacred for all Indian rituals. It is mentioned that by making the sound of the bell, the gods are invoked For making a bell, one should know the technology of bell alloy making. Unlike the qualifications required for other metal alloys, the bell metal should give a perfect, melodious and acceptable musical sound. Hence this alloy preparation attracts special attention of metallurgists. Bell metal is a copper alloy mentioned in Arthasastra as tala. Method for separating copper from bell metal is described in Rasaratna samucchaya (8.37)

स्वल्पतालयुक्तं कांस्यम् वंकनालेनताडितं मुक्तरंगं
हि तत् ताम्रं घोषाकृष्टं उदाहृतं

Svalpathaalayukthatm kaamsyam vankanaalena thaaditham
muktharangam hi thath thaamram ghoshaakrushtam udaahrutham

Molten bell metal is heated with a little tala or orpiment blown with a bent tube and freed from Ranga of tin What we get is bell metal extracted copper. The word ghoshakrushtam is specific for the sound making alloy which is now known as bell metal. Even in Vedas bells have been mentioned frequently. Millennia old bells can be seen in many temples.

Panchaloha: This is the most common alloy used in the manufacture of idols. For the last three thousand years Panchaloha (which literally means five metals) was used for

making idols. Panchaloha idols with a historical background of two millennia could be excavated by archaeologists. Many ancient Sanskrit and regional literature are important sources of information on this alloy making. The artists who perfected this technology are many in South India. The traditions have been maintained and nurtured for centuries. Charaka samhita gives the explanation of Panchaloha as follows (1 70)

सुवर्ण समलाः पञ्चलोहाः ससिकताः सुधा ।
मनः शिलाले मणयो लवणं गौरिकाञ्जने ।

Suvarna samalaa. panchaloha: seesakathaa: sudhaa
mana: silaale maneyo lavanam gouri kaanchane

In Panchaloha, gold and separately copper, silver, tin, lead and iron are mixed. Its composition is also described as follows:

कांस्य अर्करीति लोह अहिजातं तत् पर्तलोहकं तदेव
पञ्चलोहाख्यं लोहविद्भिः उदाहृतं ।

Kaamsya arkareethi loha ahijaatham thath parthalohakam
thadeva panchalohaakhyam lohavidhi udaahrutham

An alloy of five metals of tin, copper, brass, iron and lead is panchaloha (Rasaratna samuchaaya (5.212).

Metal seal : Bruhat samhita (57-17) gives this explanation to the metal seal:

अष्टौ सीसकाभागाः कांसस्य द्वौ तु रीतिकाभागः
मयकथितो योगः अयं विज्ञेयो वज्रसंघातः।।

Ashtow seesakabhagaa. kaamsasya dow thureethikaa bhaaga:
mayakathitho yoga: ayam vijneyo vajrasanghaatha:

Eight part lead, two part bell metal and one part brass alloy has been described by Maya as the Vajrasanghatha metal seal

In modern metal science metallic seal is commonly used.

Pure metals

Copper : Copper is one of the most common metals known to human race. Tamra is the word adopted in Yajurveda for copper. Historically the copper age has been given importance on the basis of the technological capability in the progress of human civilization. Keeping away the literature, one can see that historically copper metallurgy is the oldest in India. Mehargarh excavation showed that the copper samples extracted belonged to 8000 BC. One of the many samples obtained from this site has recorded the production date which can be 7786 +/- 120 BC i.e 10000 years back! The number of copper and copper alloy samples obtained from various archaeologically important sites were about 2500 BC.

As far as the Sanskrit literature is concerned, it appears that Arthasastra comes first in the descriptions of copper. The earlier mentioned are the description of ores of copper by Kautilya in Arthasastra. All the 'pana' coins inevitably contained copper as the major component. Mashakam contained 11 parts by weight of copper (4 parts silver and 1 part other metal) Harappan copper was 99% pure and Mohanjo daro copper 97%. Ancient technology should have been excellent to get this level of purity for the copper.

Interestingly, copper kilns used during the post Vedic period can be seen in the mine sites even now. Kiln residue obtained from many sites showed that removal of iron from copper, during the extraction of the latter was carried out by adding the flux. Large amount of iron silicate could also be seen. This shows that the copper extraction method followed was technically high standard.

Iron : Evidences available from Mesopotamia, Egypt, and Afghanistan show, that during 3000 - 2000 BC efforts were made to produce iron. Similar trails were conducted in Cyprus during 1600 B C. Upto 1600 BC the Greek and the Mediterranean

people could not produce iron. After putting all the evidences together, it was concluded that till 1200 BC iron production was not conducted successfully anywhere in the world. But in Yajurveda mention of iron as syamam can be seen.

In Susrutha and Charaka samhita, use of iron to treat anaemia as an asavam (tonic) is mentioned. This asavam is known as Loha asavam. It is described as follows:

युक्तानि लोहवत्कुम्भे स्थितानि घृतभाविते
संवत्सर निधेयानिवपल्ले तथैव च ......
Yukthaani lohavathkumbhe sthithaani ghruthabhaavithe
samvatsara nidheyaaniapalle thathaiva cha....

For years together, ghee is stored in iron vessel and that is used for the preparation of iron asavam.

Archaeological samples obtained from five regions of North India shows that by 1200 BC iron was commonly produced in India. One sample obtained from Ahar was dated at 1300 BC. C_{14} carbon dating studies showed that iron samples obtained form Leobarn, Pirak, Hallur, Tamragarh, Atranjikhera were produced between 1600 - 1300 BC. The use of iron for making alloy is discussed in Arthasastra. Iron ores, probably hematite and magentite have been described in detail in this book. They are Surumba and Vaikruta dhatus. Their colour and texture resemble perfectly with the ancient explanations and modern observations.

मुण्डं तीक्ष्णं च कान्तं च त्रिप्रकारमयस्मृतं
Mundam theekshnam cha kaantham cha thriprakaaramayasmrutham

Three important classes of iron has been mentioned in the text books of Maya,Kanta Loha, Teekshana Loha and Mundaloha. (Rasaratnasamuchhaya 69)

भ्रामकं चुम्बकं चैव कर्षकं द्रावकं तथा एवं

चतुर्विधं कान्तं रोमकान्तम् च पञ्चमं ।

Bhraamakam chumbakam chaiva karshakam dravakam thathaa evam chathurvidham kaantham romakaantham chapanchamam

Kanta Loha, which is soft iron, has the following five categories: bhramaka, chumpaka, karshaka, dravaka and roma (Rasaratna samuchhaya 84)

... षड्विधं तीक्ष्णमुच्यते .. खरलोहमुदाहृतम् .. सारलोहं तदीरितम् ..

Shadvidham theekshnamuchyathe ..... kharalohamudaahrutham .... saaraloham thadeerutham

Teekshna loha (which is carbon steel according to modern definitions), are of six types: khara, hrunnala, trivrutta, vajra, kala., etc. (Rasaratna samuchhaya 75)

मृदु कुण्ठं कडारं त्रिविधं मुण्डमुच्यते

Mrudu kuntam kaddaram thrividham mundamuchyathe

Mundaloha which is the cast iron is of three kinds: mrudu, kunda and kadara. The quality of roasted iron and rust of iron is compared here. This gives a very important information of the knowledge similar to chemical composition of both of the compounds as iron oxide (Rasaratna samuchaya 148)

ये गुणामारिते मुण्डे ते गुणा मुण्डकिट्टके
तस्मात् सर्वत्र मुण्डरं रोगशान्त्यै प्रयोजयेत् ।

Ye gunaa maarithe munde the gunaa mundakittake
thasmaath sarvathra mundaram rogasaanthyai prayojayeth

The qualities of air-roasted iron and the rust of iron are the same. Therefore the latter was also acceptable for medicinal purposes.

Bruhat samhita (50.26) explains the method of carburisation of iron. Carburised iron weapons were spotted in many places

by the archeological study groups. The process of carburisation gives hardness and sharpness for weapons. This subject has been discussed in detail by Bhatia [80b].

क्षारे कदल्या मथितेनयुक्ते दिनोषिते पायितमायसं यत् सम्यक् शितं चाश्मनि नैति खड्ग न चान्यलोहेषु अपि तस्य कौलठयम्

Kshaare kadalyaa mathithenayukthe dinoshithe paayitha maayasam yath samyak sitham chaasmani naithi khadga na chaanyaloheshu api thasya kowlatayam

The iron weapon treated with a day old banana drink made of burnt powder of bananas mixed with butter milk and then sharpened properly, will not break in stones, nor becomes blunt on other instruments.

The quality of Indian steel has been referred to by Ktesias who was in the court of Persia in the 5th century BC. Swords made in India were purchased by Persian kings. Alexander the great was said to have received 30 pounds of Indian steel in 326 BC from King Porus for making Damascus swords.

Iron metallurgical process and alloy preparations in ancient India was common. Iron is the common metal known to have the highest melting point nearly 1500° C. Indians could achieve this temperature level for iron processing. Nowadays coal is used for the purpose whereas in ancient period, fuel combinations used for achieving this temperature is yet to be found out.

Silver : Metallurgical process of Silver was known at least from the period of Mohanja daro civilization. Silver articles were obtained from there. Arthasastra describes silver as follows: (2:13:31)

तुत्थोद्गतं गौडिकं काम्बुकं चाक्रवालिकं च रूप्यं श्वेतं स्निग्धं मृदु च श्रेष्ठं विपर्यये स्फोटने च दुष्टं तत् सीस चतुर्भागेन शोधयेत् उद्गत चूलिकमच्छम् भ्राजिष्णु दधिवर्णम् च शुद्धम् ।।

Thutthodgatham gouddikam kaambuka chaakravalikam
cha roopyam svetham snigdham mrudu cha sreshtam
viparyaye sphotanam cha dushtam thath seesa chathurbhaagena sodhayeth
udgatha choolikamaccham bhraajishnu dadhivarnam cha suddham

Silver has the colour of jasmine bud, it contians a lot of lead, it may have the colour of sky, it is white, soft and also precious. If mixed with 4 parts of lead, the alloy will have the colour of fresh curd.

Arthasastra also describes the purification of silver (2:13:31)

तारमपशुद्धम् वा अस्थितुथे चतु: समसीसे चतु: ।
कपाले त्रि: गोमयद्वि:! एवं सप्तदशतुत्यातिक्रान्तम्
सैन्धविकयोज्वालितं एतस्मात् काकण्युत्तरा, पसारिता .....

Thaaramapasuddham vaa asthithutthe chathu: samaseese chathu:
kapaale thri: gomayadi evam saptha dasathuththaathikraantham
saindavi kayojvalitham ethasmaath kaakanyuttharaa pasaarithaa..

Impure silver is mixed with bone powder, 4 parts lead, 4 parts sand, 4 times cow dung, 3 parts kopal together 17 parts, mixture is taken in a kiln It is heated and mixed with salt and sand and further melted. To the silver, thus obtained some gold is also added for getting shining appearence.

This is the actual process adopted for the removal of impurities such as lead, iron, etc. from the silver during its extraction process. Impurities or 'adulteration' of silver has been explained based on physical characteristics, in Arthasastra (2:14:33)

रजतानां विस्रं मलग्राहि परुषं प्रस्तीतं विवर्णम् वा दुष्टमिति विद्यात् ।

Rajathaanaam visram malagraahi parusham
prastheetham vivarnam vaa dushtamithi vidyaath

If silver happened to be mixed with lead, it will have a bad smell. The alloy will be rough, less coloured, low shining, etc.

This silver is to be purified with the bone powder in a furnace.

The science behind this process says that the addition of bone gives the source of calcium to remove the impurity to convert them as calcium salts. Detailed description of silver alloys are given in the above chapter as follows (Arthasastra 2:13 31)

त्रयो/ंशास्तपनीयस्य द्वात्रिंशद्भागश्वेततारमूर्च्छितं तत् श्वेतलोहितकं भवति ताम्रं पीतकं करोति । तपनीयमुज्वाल्य रागत्रिभागं दद्यात् पीतरागं भवति श्वेततारभागौ द्वावेकस्तपनीयस्य मुद्गवर्णं करोति कालायसस्यार्द्धभागाभ्यक्तं कृष्णं भवति प्रतिलेपिना रसेन द्विगुणाभ्यक्तं तपनीयं शुकपत्रवर्णं भवति तस्यारम्भे रागविशेषेषु प्रतिवर्णिकां गृह्णीयात्

Thrayoamsaasthapaneeyasya dvaathrimsath bhaaga svethathaarmoorchitham thath svethalohithakam bhavathi / thaamram peethakam karothi thapaneeya mujvaalya raagathribhaagam dadyaath peetharaagam bhavathi svetha thaara bhaagow dvaaveka sthapaneeyasyaa mudragavarnam karothi kaalaaya sasyaarddha bhaagaabhyaktham krishnam bhavathi prathi lopinaa rasena dvigunaabhyaktham thapaneeyam sukapathravarnam bhavathi thasyaarambhe raagaviseshesbu prathi varnikaam gruhneeyaath

Three parts of copper and 28 parts of silver give silver with sweta lohita colour . Three parts gold and 28 parts silver give silver with peetha raga colour. Two parts of silver and 1 part of gold give silver with mudga (green gram) colour. Two parts silver, 1 part gold and 1/6 iron gives silver with blackish colour. This alloy mixed with mercury gives silver with golden bird's feather colour.

रूपस्य द्वौ भागावेकः शुल्बस्य त्रिपुटकं तेनाकारोद्गतमपसार्यते तत् त्रिपुटकापसारितं, शुल्बेन शुल्बापसारितं, वेल्लकेन वेल्लकापसारितं, शुल्बार्धसारेण हेम्ना हेमापसारितं ।

Roopasya dvow bhaagaaveka: sulbasya thriputakam
thenaakaarodgathamapasaaryathe thath thriputakaapasaaritham,
sulbena sulbaapasaaritham vellakena vellakapasaaritham
sulbaardha saarena hemna hemaapasaaritham

Alloys of two parts of silver and 1 part of copper is known as triputakam. One part iron and 1 part silver is known as vellakam. One part iron, 1 part silver and 1 part gold is known as vellakapasaritham. One part copper and 1 part gold is known as hemapasaritham.

Archeological studies have shown that silver from Mohanjo daro has a purity 94.5%. Alloy of silver is also described in Sanskrit literature other than Arthasastra. (Rasarnava 12.42.2)

चतुर्थसारं कनकं दिव्यं तन्मातृका समं
Chathurtha saaram kanakam divyam thanmaathrukaa samam

Twentyfive percent gold with silver have the colour of pure gold (Rasarnava 7.56.2)

विक्रियार्थं तु रजतं मात्रा विज्ञायभावयेत्
Vikriyaartham thu rajatham maathraa vijnaayabhaavayeth

For sales purposes the above alloy can be further mixed with silver (Rasarnava 12.49.2)

Detailed study on this subject has been reported in Indian Journal of the History of Science [11].

Mercury : Rasachikilsa is primarily focussed on mercury and its various products. Explanations on mercury can be seen in almost all the Ayurvedic and rasa books. Among the metals discussed in Sanskrit literature, mercury gets prominence. A number of alloys were also prepared using mercury. Mercury when mixed with noble metals give the amalgam, i.e these metals get dissolved in mercury. These amalgams or alloys were

prepared, both for making ornaments and for medicinal purpose. Unlike other metals mercury has an important characterstics. Mercury is a liquid metal which is obtained dierectly by distillation as condensed liquid drops. The technological knowledge of mercury and its extraction is different from that of other metals. Knowledge of mercury definitely goes back atleast to 700 BC, the period of Susrutha because, Susrutha samhita and charaka samhita contain information of this metal. The metal extraction is clearly mentioned as distillation and it is described in Rasaratnakara (37)

दरदं पातनायन्त्रे पातितश्च जलाशये ।

Daradam pathnaayanthre paathithascha jalaasaye

Just like drops of water falls, the mercury drops fall from the distillation equipment. The same is the modern procedure adopted for the production of mercury. Distillation of mercury and its amalgam formation have been described in Rasaratna samucchaya (8.64)

मर्दित पारदस्य यन्त्रस्थितस्य ऊर्ध्वम् अधश्च तिर्यक् निर्यातनं
पातनं संज्ञं उक्तं वंगाहि सम्पर्क कञ्चुकघ्नम्

Marditha paaradasya yanthrasthithasya oordhvam adhascha thiryak niryaathanam paathanam samjnam ukthaam vangaahi samparka kanjukaghnam

When the refined ore of mercury (paradam) is heated in a distillation set up the vapour moving up, down and sides, get condensed and drops are collected, which when reacted with vanga gets solidified.

Mercury ore is heated in the modern process to get the metal vapours. Mercury is amalgamated with gold, silver, and other metals, resulting in the solid alloy formation.

In Rasaratna samucchaya, distillation of mercury has been discussed (3.141,144)

दरदः पातयन्त्रे पातितश्च जलाश्रये तत् सत्वं सूतसंकाशं जायते नात्रसंशयः

Darada. paathayanthre paathithascha jalaasraye
thath sathvam suthasankaasam jaayathe naathrasamsaya:

When distilled its satwa (essence) is relased by cooling with water which is suta or mercury. It has the property of fixing materials.

A commentary on the above lines says that the above statement is for zinc and not for mercury. Since similar distillation method is adopted for zinc also, which resembles technologically mercury production, the statement remains as a scientific fact. But zinc is solid in nature whereas mercury is liquid. The explanation 'on drops' is given it appears that the description is on the distilation of mercury.

Mercury has many other uses, even during olden days. One such line is mentioned in Aryabhateeya by Aryabhatta I in 499 AD in which he has directed the use of mercury for a perfect rotation of the golayantra (globe). The quotation has been given earlier, in the astronomical part of this book. The most important use of mercury and its compounds are for the rasachikisa as a medicine.

Lead: Lead is a blackish flexible metal and solid at normal temperatures. Rasaratna samucchaya (5.171) gives this definition for the lead:

हुतद्रावं महाभारं छेदे कृष्णसमुज्ज्वलं पूतिगन्धम् बहिः
कृष्णं शुद्धम् सीसं अतः अन्यथा ।

Druthadraavam mahaabhaaram cchede krushna samujvalam
poothigandham bahi: krushnam suddham seesam atha: anyathaa

Readily fusible, very heavy, having a black and bright appearance on fracture, having off, foetida odour and black extension is naga which is the lead. Lead obtained from the archaeological sites of Lothal has a purity of 99.5% and that obtained from

Mohanjo daro was 99.7%. Quotations given earlier from Arthasastra, refer to various alloys prepared from lead. Thus it can be seen that lead and its alloys were well known, and alloying them with bell metal is mentioned in Bruhatsamhita of Varahamihira (57.1-7) and "An alloy of eight parts of lead, two parts of bell metal and one part of brass has been mentioned by Maya as Vajrasankhata, a metal joining seal".

In Rasaratna samucchaya (3.146) the use of lead and its ore products as hair dye is mentioned.

सदलं पीतवर्णम् गुर्जरमण्डले अर्भुदस्यगिरे
पार्श्वे जातं मृद्दारश्रृंगकं सीससत्वं जनमुत्तमम् ....
Sadalam peethavarnam gurjaremandale arbhudasyaa gire
paarsve jaatham mruddarasrungakam seesasathvam janamutthamam

Seesa satram or cinnabar (?) was known to occur in two varieties; inferior and super grades, which come from Gurjar province near the Abida mountains, coloured yellow with lamella, yielding lead and for preparing hair tonic.

The use of lead, their oxides and a variety of derivatives for dyes is a common practice now. In Rasarnavam (7.112b) extraction method of lead is thus mentioned while explaining the metallurgical process for tin (described earlier). "....... Similarly lead can be prepared from its ores using bones of elephant". The first part of these lines refers to the reduction of tin oxide (ore of tin) using buffalo bones.

Here too the role of the calcium present in the bone (acts as flux) is to remove the impurities after converting it into slag, calcium silicate. In modern times calcium is directly used as calcium carbonate, oxide etc. for the production of lead.

Zinc : Zinc is an ash coloured flexible, low melting metal. Detailed description of this metal has been given under brass.

Zinc components and its alloys with the copper dating back to 3000 BC, were obtained during excavation. These samples have very specific composition of copper and zinc.

The distillation process of zinc extraction is described in these verses in Rasaratna samucchaya

वृन्ताक आकार मूषायां नालं द्वादशाकांगुलं दत्तूर पुष्पवत् च ऊर्ध्वं सुदृढम् शिलाष्टपुष्पवत् अष्टाङ्गुलं च सच्छिद्रम् सास्यात्
वृन्ताकमूषिको अनया खर्परादीनां मृदुनां सत्वमाहरेत्

Vrunthaaka aakaara mooshaayaam naalam dvaadasakaangulam datthura pushpavath cha oordhvam sudruddam silastia pushpavath ashtaangulam cha sacchidram saasyaath vrunthaakamooshiko anayaa kharparaadeenaam mrudunaam satvamahareth

Brinjal shaped crucible is attached with a 12 angula (average diameter of a finger) long tube over it like an inverted flower of dhattura. A hole of 8 angula is made in the tube. This crucible is used for the extraction of satva (metallic Zinc) from soft drug of Kharpara (Rasaratna samucchaya 10.22-23)

A series of such crucibles were arranged in a big heater and the crucibles were connected together. The conical datura flower shaped condensers, converge the vapours during the process of condensation. Thus the solid zinc is obtained when the vapour condenses.

Dozens of zinc crucible furnaces were found in different parts of Rajasthan, many of them, dating back to 3000 to 2000 BC. The Sanskrit lines given above and the observation agree each other. Modern process is also the same, but larger crucibles are used.

In Rasaratnakara (31,32) details of zinc production is given:

मूकमूषागतध्मातं टङ्कणेन समन्वितं सत्वं कुटिलसंकाशं पतते नात्रसंशय:

Mookamooshaagathadhmaatham tankanena samanvitham

satvam kutila sankaasam pathathe naathra samsaya:

There is no doubt that this process yields an essence of metal of the appearance of tin.

Tin prior to purification resembles the metallic zinc. Zinc is like tin and it convertes copper into gold (golden coloured brass). Dr. A. K. Biswas [12] in the Indian Journal of the History of Science, gives the explanation on the composition of different types of brass obtained from the various archaeological sites of the Indus valley civilisations during the Vedic period. Which was produced alloying copper with metallic zinc. Hence zinc metallurgy was known even to the vedic people.

A sheet of zinc was excavated from Agora, a town in Athens, Greece. It has been proved that the metal was taken from Taxila, India. This sheet was produced in the 3rd century BC.

Hundred metre deep mines of South Lode when examined using C^{14} dating studies revealed that, the mine was functioning in full swing in 1260 BC. This mine is situated in the modern Rajpura Dariba area of Rajastan.

It has been explained by the experts that the metallurgy of zinc and related technology was taken to the West from India during the 5th - 6th century BC and further later during the 18th century AD.

There is a history of 'smuggling' the technology of zinc production to the West. The details are well documented. In 1597, Libavius received Indian zinc which he called Indian/ Malabar lead [13]. He was uncertain what it was. Paracelsus in 1616 AD is generally credited to have given the name 'zinc' to this 'Malabar lead'. Large-scale export of metal from India to the West was common during the latter half the 17th century Detailed study of zinc was reported from Europe only in 1695 by Rosco of Hamburg. He produced the metal from its ore, calamine. In

1751 Postlewayt's Universal Dictionary of trade and commerce has to admit ignorance how zinc was made in the East. showing that till then knowledge on the zinc metallurgy had not reached the West. William Champion of Warmley of United Kingdom experimented and applied for a patent for the zinc metallurgy in 1743. It was found later that Indian knowhow was copied and the patenting plagiriasm was reported with criticism as follows: Champion was notoriously close with details of the Indian process at Zawar mines (in Rajastan), and possibly a third party described the general principle of the process to Champion" and the patent application was reported rejected.

The technology for zinc production was exported from India in a similar way the metals and ores were exported. Many tourists and travellers have played the role of "knowledge carriers".

Beckman a scholar from the United Kingdom has reported that an Englishman has gone to India, the 17th century to discuss the process of manufacture of zinc and returend with details of distillation. Prof. Poster wrote : "A Dr. Lane seems to have smelted zinc at his copper workshop in Sansea as early as 1720 and this was done after visiting Zawar in India"[94]. these writings show that the knowledge of the zinc metallurgy has been transferred from India to the developed nations. The technology might have modified and updated but the essence of discovery is basically remain INDIAN.

Tin: Tin has been discussed in almost all the Lohatantra books as trapu or vanga. Tin alloyed with copper to get bronze has been discussed in the first part of this chapter. Two types of tin exist in nature which are interconvertible with temperature and they are alpha and beta tin. Explanation of two types of tin in Rasaratna samucchaya (5:153-154) is as follows:

क्षुरकं मिश्रकं चेति द्विविधम् वङ्गमुच्यते क्षुरकं तत्रगुणै: मिश्रके न हितं मतं धवलं मृदुलं स्निग्धम् दन्तद्रावं सगौरवं नि:शब्धम् क्षुरवङ्गं स्यान् मिश्रकं श्यामशुभ्रकं

Kshurakam misrakam chethi dorvidham vangamuchyathe kshurakam thathra gunat: misrake na hitham matham dhavalam mrudulam snigdham danthadraavam sagouravam nissabdham kshuravangam syaan misrakam syaamasubhrakam

There are two types of tins known as kshurakam and misrakam. High quality tin is known by the name kshurakam and not much accepted one is misrakam. White, soft, flexible, tooth types, dense, without making metallic sound is the Kshurakam and the misrakam is blackish white and clean.

According to the descriptions given, it can be concluded that kshurakam is beta tin and the misrakam is alpha tin. It is in this century that the modern world came to know about the two types of tin.

Excavated samples of bronze were available even from Mohanjo daro and Harappa. The percentage proportion of tin present in bronze alloy was 4.5 to 13.2% and 23 numbers of such articles were excavated from there. Tin metal extration, from the period of the Mohan Jodaro civilization, is existing here.

Rasopanishad is a book written in the beginning of the 11th centruy whose 13th chapter exclusively describes the method of tin extraction. The title of the chapter of Vangastambhana sodhanam which means the production of tin.

Rasarnava a book written in the 11th century gives the extraction process of tin as follows:

महिष्यस्थिचूर्णेन वापात्तन्मूत्रसेचनात् वंगशुद्धम्
भवेदग्नौ नागो नागास्थिमूत्रत:

Maahishyasthi choornena vapaatthanmoothra
sechanaath vangasuddham bhavedagnow naago naagasthi moothratha:

By the use of powdered bones of buffalo in the crude molten metal and by sprinkling its urine over it, tin is produced and purified (Rasarnavam 7 112)

As explained earlier the addition of the bones, the flux of calcium is obtained which gets reacted with sand, the impurity, to form calcium silicates which can be removed as the slag from molten tin. The organic matter present in the bone acts as carbon source to reduce the oxides of tin, to get refined metal.

The modern tin metallurgy came to be known in Europe only in the 16th century during the period of Agricola [85], whereas the Indian descripions of the process are centuries older than this period.

Vijay Deshpande has reported a series of scientific studies carried out in tin metal, on the basis of the explanations given in Rasopanishad (Indian Journal of the History of Science)[86]. In the 13th Chapter of Rasopanishad, a series of plant products used as flux and reduction process of tin stone (tin oxide) are discussed. These plant products act as carbon for reducing the tin oxide. Instead of plant products, carbon/coal is directly used in the modern method. All the alloys mentioned in the text were prepared by Prof. Pandey and proved that those explanations are true. A variety of the process are given for converting tin into golden coloured alloys. These alloys are produced using different proportions of mica, copper, silver, mercury, etc.

Product obtained from tin is also described on Rasaratna samucchaya (20-2, 21-1)

वङ्गाम्हेमसहितं विमलं चान्धमूषितं निर्वहितं कूर्पतुल्ये भवेन्मरतकप्रभम्
Vangaamahemaahitham vimalam chaandhamooshitham
nirvahitham koorpathutthe bhavenmarathaka prabham

Tins with mica and equal amount of gold is placed in a closed crucible along with vimala (a plant product) and roasted. It is accomplished in the koorpathootha to get a material resembling emerald in colour and lustre. Possible elements in this alloy are gold, zinc, copper and some extractive from the crucible. Here the crucible also act as a source of fine components. Tin alloys were obtained from Lothal, Mohanjo daro, Harappa and other archaeological sites, substantiating the knowledge of tin and its alloys.

Gold : In Vedas, frequent use of the synonyms of gold stands as ample proof of knowledge. A variety of gold alloys were also mentioned. Arthasastra describes five types of gold (2:13:31)

जाम्बुनदं शातकुम्भं, हाटकं, वैणवं शृङ्गशुक्तिजं, जातरूपं
रसविद्धाकारोद्गतं च सुवर्णं

Jaambunadam saathakumbham, haatakam
vainavam srungasukthijam, jaatharoopam
rasaviddhaakaarothgatham cha suvarnam

Jambunadam, satakumbham, hatakam, vainavam, srungasuktijam are five names given in the above lines for five types of gold, based on the process or the place from where these gold are obtained and produced.

Minor compositional variation can be possible in processing methodology adopted. Similarly composition can also vary depending on the mineral/used for the gold production which might have resulted in the variation of quality. Gold purification has been explained in Arthasastra (2:13:31)

तपनीयं ज्येष्ठं सुवर्णं सुरागं, समसीसातिक्रान्तं पाकपत्र पक्वं
सैन्धविकयोज्वलितं नीलपीतश्वेतहरित शुकपोतवर्णानां प्रकृतिर्भवति
तीक्ष्णं चास्य मयूरग्रीवाभं श्वेतभंगं चिमिचिमायितं काकणिकः सुवर्णरागः

Thapaneeyam jyeshtam suvarnam suraagam
samaseesaathikraantham paakapathra pakvam saindavi
kayojvalitham neelapeetha svethaharitha sukapotha varnaanaam
prakruthirbhavathi theekshnam chaasya mayoora greevaabham
svethabhangam chimichimaayitham kaakanike suvarnaraaga:

Different types of gold having various colours mixed with lead and made into sheets, mixed with cow dung cake, sand of Sourashtra and salt and burnt. This will give the best colour for gold, in bluish white, greenish, dove coloured, etc., as desired. Additions of iron gives many other colours including yellowish black, etc.,

Many alloys of gold for coin making are described earlier in this chapter. One such alloy referred to in Bharadwaja's Amsubhodhini [87] is prepared as follows.

ताम्रषोडशके चुलीताम्रषोडशकं तथा । द्वादशस्वर्णलोहेषु
हिरण्याष्टकमेव च गोदन्तीतालषट्कं च सूतपन्यकमेव च ।
सूर्यकान्तशिलाषट्कमेतान् संयोज्य भागशः क्रमान्माघिमभूषायां
सपूर्याथ यथाविधि । कूर्मव्याटिकामध्ये स्थाप्यैगलादिभिः क्रमात्
द्वात्रिंशदुत्तरचतुश्शत कक्ष्योष्णमानतः गालयित्वा यंत्रमुखे तद्रसं पूरयेत्क्रमात्

Thaamrashodasake chooletbamra shodasakam thathaa
dvaadasa svarnaloheshu hiranyaashtameva cha
godanthee thaala shatkam cha sootha panyakamevacha
sooryakaantha silaashatkamethaan samyojya bhaagasa:
kramaanmaaghimamooshaayaam sampooryaathaa yathaavidhi
koorma vyaatikaa madhye sthaapyengalaadhibhi kramaath
dvaathrimsaduttharachathussatha kakshyoshnamaanatha:
gaalayithvaa yanthramukhe thadrasam poorayethkramaath

Eight parts of potassium iodide, 16 parts of copper of chulithamra grade, (one of the 16 grades of copper known), 8

parts of gold namely hiranyaka grade one of the 12 grades of gold known 6 part of arsenic sulphide, 5 parts of mercury, 6 parts of quarts in a crucible of tortoise shape and melted at 432° temperature and then pour the molten alloy into the mould .

Detailed study on this carried out by Gore has been published in the Indian Journal of the History of Science[17]. Thus, the golden (and other metallic) alloy preparation is given for different applied purposes too.

Sanskrit literature carry a lot of information on this subject. Many of these alloys and some of these methods might not even have come to the notice of the modern scientists. Hence it is worth-while to peruse into the subject by which one can fetch better and more useful information on metals and alloys.

Thus the evidence on the theoretical and technological metal processing capability existed in ancient India is an important and novel source of 'new old knowledge' to the modern metallugrists and scientists. It is not only a matter of pride but also many new ideas still exist unexplored in these books Let the modern scientst look into these literature as one among the sources of knowledge to discover and rediscover new products and technologies from ancient treasures.

Thus, anyone can see, from the information presented here, that:

There were hundreds of original books written in Sanskrit dealing with the subjects of mathematics, astronomy and metallurgy.

Hundreds of commentaries were written in different languages and in Sanskrit by ancient Indian Scientists on the above books, which also contained original scientific matter.

Many of these scientific books and information were transported / smuggled / taken / donated / to foreign countries during, before and after the renaissance period.

Many of these books were translated into foreign languages by scholars. Original and translated books were spread to different countries.

During the renaissance period many European scholars studied these books and brought into light the original scientific content in them, some of which have been utilised by the Europeans and others for developing new knowledge

In these books, information starting from numerals to most complex theorems and a variety of their applications are presented very systematically

- Many of these discoveries are original contributions of Indians, which are at present known in the names of the European or Western scholars. Many more theorems are still unknown to the world of mathematics even now.

The Indian concept of astronomy and geography is perfect modern knowledge, which are at par with the latest observations.

Many details available in the modern astronomical books are also available in the ancient Indian astronomical books, some of which may need more refinement

Much of the modern astronomical information has its base in the Indian astronomical knowledge perfected through scientific observations.

Some of the latest views on modern astronomy perfectly agree with the knowledge which originated in India thousands of years ago.

Much of this knowledge, has been obtained as a result of the original experiments, studies and keen observations.

A variety of instruments have been explained for the calculation of the astronomical data and various other parameters. •

Mines, minerals, metals, ores, etc are described in detail, in Sanskrit literature which are substantiated by the archaeological observations, and literary descriptions.

The solid proof of the metallurgical capability available are from the archaeological sources of these metals and alloys from sites spread over this nation.

Detailed descriptions available in Sanskrit literature stand as added support to the science of metals, and alloys.

Thus it can be concluded that hundreds and thousands of modern scientific concepts were known to the ancient Indians....... !!

Let us study more about it. Understand every merits from that, utilise all useful information for a better modern life. Our, scientific heritage is the fruits of the experiences of great scientists whom we call Rishis.

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